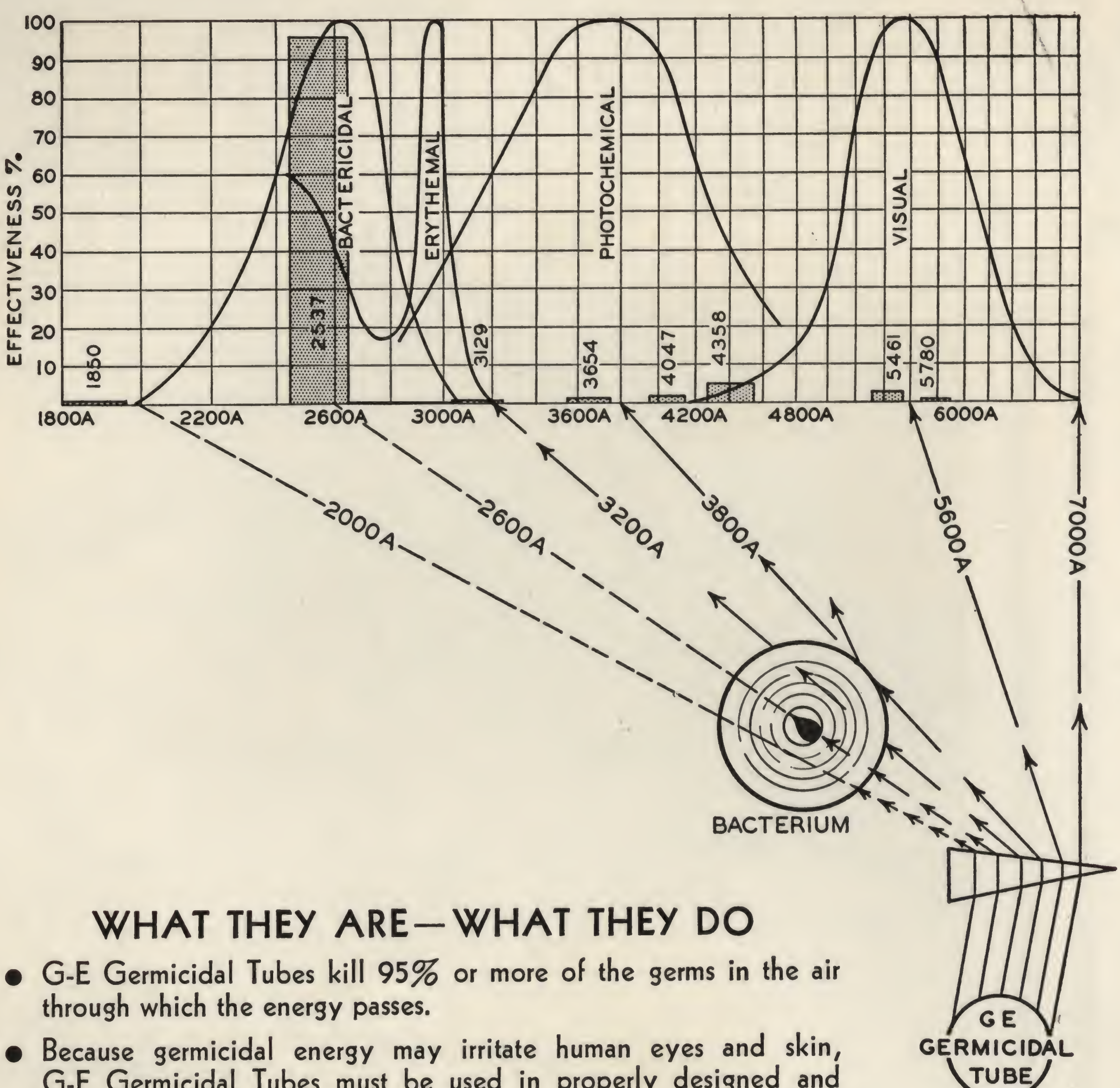
ULTRAVIOLET AIR SANITATION

GENERAL ELECTRIC

ENGINEERING DIVISION, LAMP DEPARTMENT



WHAT THEY ARE—WHAT THEY DO

- G-E Germicidal Tubes kill 95% or more of the germs in the air through which the energy passes.
- Because germicidal energy may irritate human eyes and skin, G-E Germicidal Tubes must be used in properly designed and correctly installed fixtures. Usually the tubes are placed to disinfect the area above eye level of a room.
- The number of germs in the air is reduced as disinfected air from upper areas circulates down to breathing areas. Ultraviolet energy cannot prevent respiratory infections being spread by close contact. (This is called direct droplet infection.)
- The Council on Physical Medicine of the American Medical Association has accepted G-E Germicidal Tubes for air disinfection in nurseries, wards and operating rooms in hospitals.

ULTRAVIOLET AIR SANITATION

by

L. J. Buttolph

and

Howard Haynes

GENERAL ELECTRIC

ENGINEERING DIVISION, LAMP DEPARTMENT
CLEVELAND 12, OHIO

Revised January, 1950

LD-11

TABLE OF CONTENTS

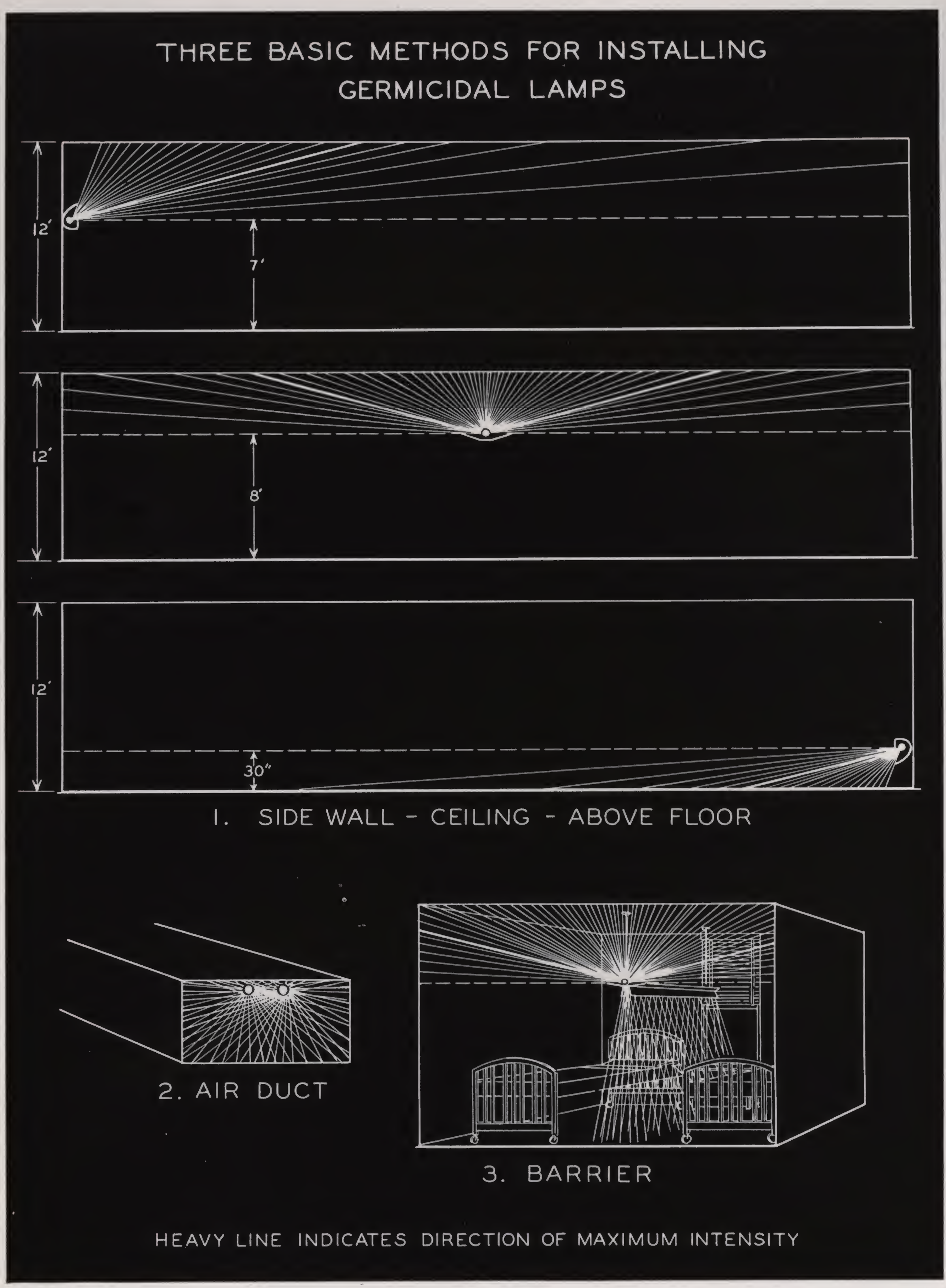

THREE BASIC METHODS FOR INSTALLING GERMICIDAL LAMPS
12'
7'
12'
8'
12'
30"
1. SIDE WALL - CEILING - ABOVE FLOOR
2. AIR DUCT
3. BARRIER
HEAVY LINE INDICATES DIRECTION OF MAXIMUM INTENSITY

Fig. 1

SECTION I

THE NEED FOR AIR SANITATION

Pasteur showed long ago that living bacteria, yeasts and molds were air-borne to spread human, animal and plant diseases. Now we know that the same is true of viruses. Now we can do something about it.

Contaminated Air

We know that such diseases as cold, influenza and tuberculosis; measles, chicken pox and mumps, are spread by air-borne germs to an extent often comparable with all the other ways combined. These are called respiratory diseases because they are caught from breathed air, not because they are diseases of the throat, nose or lungs. The air in the corridors and rooms of the best hospitals is known to contain the bacteria and viruses of nearly all the respiratory diseases of patients. Nurses and mothers wear face masks to protect newborn infants from bacteria and viruses air-borne on dust particles and in droplets of moisture. We know that childhood diseases are spread with explosive or epidemic rapidity through the air of school rooms. Municipal health officers annually urge us to stay away from crowded public places to reduce the spread of colds and influenza. We are told to smother the cough and sneeze for sanitary decency if not for propriety.

Air Sanitation

Those who have studied the problems of air sanitation or hygiene believe that we should maintain indoors in very crowded places a condition comparable with summer living—ventilation equivalent to open windows—and in less crowded places, ventilation in proportion to the crowding. They believe that air of outdoor purity is an essential part of man's environment. There is experimental evidence that ultraviolet air disinfection equivalent to summer ventilation will reduce the hospitalization from respiratory diseases 25–35% in Navy barracks.

It is important to remember that this may be all that it is possible to do by air sanitation since the so-called respiratory diseases are spread by other than air routes. They are sometimes caught in other ways than through breathing—droplet infection, physical contact, food, etc. Therefore, claims made for a specific reduction in the spread of respiratory diseases in any given instance are unwarranted. Reputable germicidal equipment manufacturers confine their claims to the provable fact that germicidal ultraviolet kills air-borne germs. To that extent, germicidal tubes are beneficial in providing improved air sanitation.

Outdoor Air for Ventilation

However polluted with dust and odors, mold spores and insects, outdoor air practically never contains hazardous amounts of bacteria and viruses of human disease. This is fortunate because dilution of indoor air with outdoor air has been our only way of providing ventilation for odor and carbon dioxide control. Until recently, it has been our only way of providing the increased amounts of ventilation, the sanitary ventilation, needed for bacterial control.

In the northern half of the United States the cost of heating, filtering and distributing outdoor air in school buildings, for example, has made it practical to provide about 20–30 cubic feet of air per minute per pupil during the winter months, but little more than that. That is good because this amount of air is about the minimum essential for odor control in crowded places. But this is bad because it is only about 1/10 what is needed for sanitary value.

Sanitary Ventilation

Twenty–30 cubic feet of fresh air per minute per pupil will, for example, provide about 1/10 air change per minute in a typical school room (25 x 30/22 x 28 x 12) seating 25 pupils, or six air changes per hour. This amount of air per minute, or rate of air change, will reduce the air contamination of the vacated room to 5% in about 30 minutes (can be done with ultraviolet in three minutes). But our respiratory disease problem is not the simple one of cleaning the air in vacated rooms. It is the complicated one, in crowded rooms, of killing or removing the bacteria and viruses as rapidly as they appear from the noses and throats, the handkerchiefs and clothing, of the occupants. It is the problem in crowded rooms of killing or removing germs within a minute or two instead of the usual 30 or more minutes. It is the problem, even in uncrowded rooms, of killing or removing or dispersing the germs fast enough to greatly reduce their chance of being

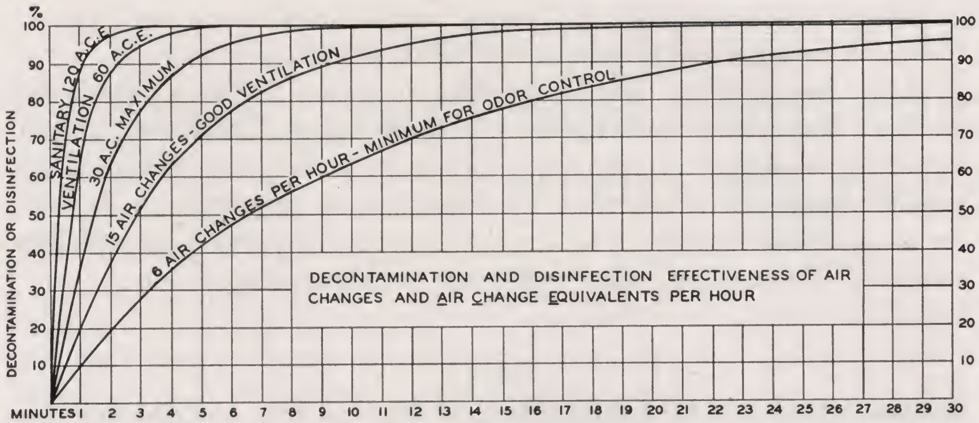


Fig. 2. Theoretical rate of air disinfection in a vacated room. Higher air change equivalents are practical only by ultraviolet air disinfection.

air-borne from a sick person to a susceptible one. This process is difficult to illustrate graphically but the theoretical rates of air cleanup in a vacated room are shown in Fig. 2.

Air Sanitation Based on Need

Air sanitation is inherent in the dispersion and dilution provided by a large volume of air. That is the natural outdoor condition. The amount of air sanitation by ventilation needed indoors depends upon the room volume, the number of people and the proportions of them ill and susceptible. It is impractical to appraise the sources of infection and the individual susceptibilities of a group of people. We can only assume that many of them are sources of respiratory infection and that most of them are susceptible. In the hospital we assume that all are potential sources of infection and all susceptible. **There double the usual sanitary ventilation is suggested.** We must also design for the maximum probable rather than the average crowding. As in ventilation for odor and industrial fume control, the basic provision must be in cubic feet of fresh air or disinfected air per person. The amount needed is inversely proportional to the breathing space per person or directly proportional to the "crowding." The fresh air, or equivalent disinfected air, in cubic feet per minute, per person (cfmp) is then directly proportional to the number in a room (n) and inversely proportional to the room volume (v). Expressed as a formula with an empirical constant this is

(1) $\text{cfmp} = 100{,}000\ n/v$.

The total room ventilation (cfmr) is the ventilation per person, cfmp, times the number of people.

(2) $\text{cfmr} = \text{cfmp} \times n = 100{,}000\ n^2/v$.

See Appendix Fig. A17 for a chart of formula (2).

These formulae and Fig. A17 can be used to calculate the sanitary ventilation of nearly every practical combination of room size and use.

These formulae are based on a room occupancy of six or more hours per day. How short the occupancy may be to reduce the need of sanitary ventilation is dependent upon the crowding but otherwise not known. A tentative suggestion is to reduce the ventilation in proportion to the time for an individual occupancy of less than one hour per day—one-half in a restaurant, for example, where half-hour lunches may be usual.

Table I

Sanitary Ventilation for Rooms (cfmr) of Various Sizes and Occupancies

Room Volume	Number of Occupants					
	2	4	8	16	32	64
160,000		*10*	*40*	*160*	*640*	*2,560*
80,000	*5*	*20*	*80*	*320*	*1,280*	5,120
40,000	*10*	*40*	*160*	*640*	2,560	10,240
20,000	*20*	*80*	*320*	1,280	5,120	20,480
10,000	*40*	*160*	640	2,560	10,240	40,960
8,000	*50*	200	800	3,200	12,800	51,200
4,000	100	400	1,600	6,400	25,600	**102,400**
2,000	200	800	3,200	12,800	51,200	**204,800**
1,000	400	1,600	6,400	25,600	**102,400**	**409,600**

Formula (2) applies directly to the practical provision of sanitary ventilation. Table I samples its application to a few conditions and Fig. A17 in the Appendix shows its application to a wide range of room sizes and number of people—from a small office to a theatre. The ventilation indicated by italicized type at the upper left of Table I is normally supplied by air leakage. The sanitary ventilation indicated by light face type diagonally up across Table I can be provided by adding mechanical ventilation or air disinfection to the normal air leakage. The sanitary ventilation called for by the rest of Table I can be provided only by adding to any practical leakage and mechanical ventilation five to ten times as much of equivalent air disinfection.

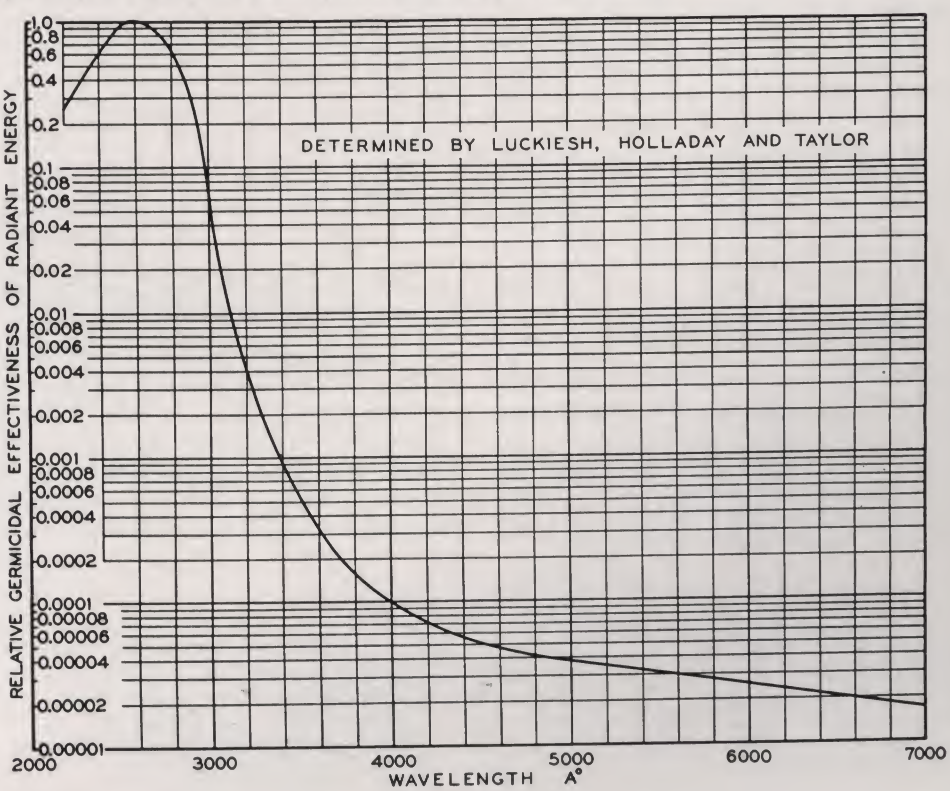
This additional sanitary ventilation can be secured through the natural circulation of the room air which has been disinfected by ultraviolet in the upper part of the room itself. This upper-air-method is, in fact, so simple and effective as to make the disinfection of recirculated air in a duct system superfluous under most conditions. The upper air method is often described as the use of the upper part of a room as if it were a recirculating duct delivering disinfected air to the lower part of the room.

SECTION II

HOW ULTRAVIOLET AIR DISINFECTION PROVIDES AIR SANITATION

The ultraviolet from the sun and from sunlamps, which reddens and tans the skin or darkens the photographic film, also kills bacteria, viruses and fungi. The shorter the wavelength the greater this germicidal effect, Fig. 3, so that wavelength 2537A from germicidal tubes is about ten times as germkilling as wavelength 2967 from sunlamps, about 4000 times as germkilling as wavelength 3650A from photochemical lamps and 30,000 times as germkilling as the most visible wavelength from the sun and from artificial light sources. Germicidal ultraviolet disinfects air by a direct killing action on the germs. These germs absorb little energy, but that little is more than they can take and they become dead instead of living dust-like particles. These sunburning, photographic and germkilling effects are produced by "exposures" made up of intensity and time; low intensity for a long time or high intensity for a short time. Practical germkilling, like most picture taking, must be done with enough intensity to secure results in seconds and minutes rather than hours and days.

Fig. 3. Relative germicidal effectiveness of ultraviolet and visible energy.



The high intensity of sunlight, even through window glass, to some extent makes up for its relatively low germkilling effect so that it has a worth while effect of disinfecting the floor dust in rooms having a large southern exposure of glass. It is important to note, however, that this effect is no more than is obtained by low intensities of germicidal ultraviolet scattered downward from the ceiling in any installation of germicidal tubes for upper air disinfection. As with sunlight, these effects are possible with ultraviolet intensities not irritating to the face and eyes only because of the long 8 to 12-hour per day exposure. Although such long exposures may be of value in supplementing the usual dust control measures and in disinfecting the air of vacated rooms, they are too slow to be of value in crowded rooms. The average life of the air-borne bacteria in a hospital should be measured in seconds or minutes, not hours or days.

Basic Ways of Using Germicidal Tubes—Fig. 1

Intensities of germicidal ultraviolet high enough to kill air-borne germs before they have had time to travel from one person to another are so irritating to the face and eyes that they must be limited to the upper and lowest parts of the rooms, to places where the faces of people may not be exposed for more than a few minutes per day, or to air ducts. These limitations lead to the three basic ways of using germicidal tubes: (1) on the side walls or from the ceiling of a room to irradiate the air above the 7-foot level, and sometimes on the side walls to also irradiate the floors and the air below the 30-inch level; (2) in an air duct to irradiate the air passing through it; (3) and in a room to irradiate all the air in it from fixtures mounted on the ceiling or side walls, and sometimes provided with baffles to restrict the ultraviolet to germicidal curtains or barriers. Disinfected air from above the head level, or disinfected air in ducts, is as good as outdoor air for room air sanitation by ventilating dilution as has already been indicated.

Lower Air Disinfection by Upper Air Irradiation

Direct air sampling shows that irradiation of the upper air in a room will keep it nearly as free of bacteria as outdoor air; as if the ceiling and walls above the 7-foot level were removed. Sampling of the lower air shows that the local interchange of air between the upper and lower levels nearly always provides a "sanitary ventilation" equal to 1 to 2 air changes per minute or 60 to 120 changes per hour. This is a reduction in the lower air contamination far more rapid than can be provided by air ducts, is such as might be produced by dilution with outdoor air through wide open windows on a windy day.

Recent studies by M. Luckiesh and Associates have shown dramatically the effectiveness of this two-stage process of air sanitation. They did continuous air sampling of the irradiated upper air at an 8-foot level and of the diluted lower air at a 4-foot level, during continuous air contamination, in excess of that humanly possible in a crowded room, by a spraying of diluted sputum. The instant the irradiation began, the concentration of bacteria in the upper air dropped rapidly to an undetectable level in about 20 seconds and remained there in spite of the continuous contamination from below, Fig. 4. This disinfection of the upper air made the air interchange immediately effective in diluting the contamination below. There was equilibrium at a low level of less than 5 per cent the initial contamination in about 10 minutes. Thereafter this air disinfection by dilution, of over 95%, was maintained indefinitely in spite of the continuous contamination by spraying of sputum.

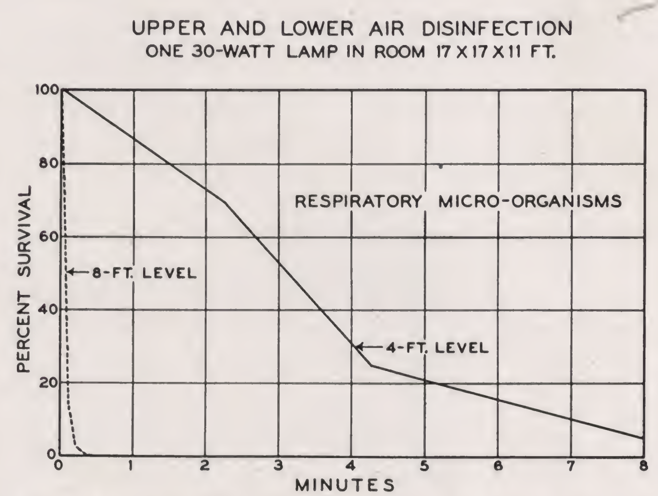
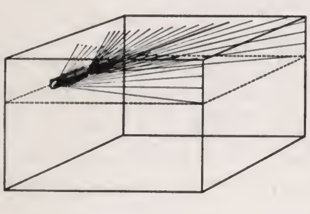
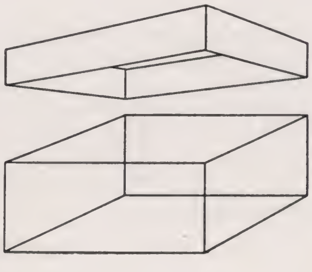
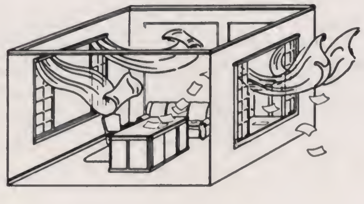


Fig. 4. Effectiveness of germicidal tubes in the upper and lower air spaces of a room with continuous bacterial contamination.

The age-old basic method of heating rooms by warm air has been possible only because of the air circulation in those rooms. This circulation is increased in occupied rooms by the body heat, breathing and movement of the occupants. These factors increase the circulation in proportion to the crowding, the contamination and the need for sanitary ventilation.







Many studies such as that by Luckiesh, and similar ones by W. F. Wells, have shown that the circulation within an occupied room offsets even such an extreme lack of uniform air irradiation as limiting it entirely to the upper part of a room. Because of the effectiveness of the circulation, irradiation of the upper half or third of a room with a given intensity of ultraviolet is equivalent to irradiation of the whole room with one-half to one-third that intensity.

Disinfection Equivalent to Air Changes

Many studies have shown that irradiation of a cubic foot of contaminated air with an intensity of 5 ultraviolet milliwatts per sq. ft. for one minute is equivalent to dilution of that same cubic foot of air by continuous mixing and displacement with a cubic foot of pure air in one minute. This unit of disinfection determined with atomized E-coli and called the "cubic foot lethe," see Appendix, is a theoretical removal or death of bacteria of 63.2%. This means, practically, that continuous ultraviolet irradiation of any given cubic feet of air volume at 5 ultraviolet milliwatts per sq. ft. is equivalent to dilution with that same number of cubic feet of pure air per minute.

This leads to a direct method of calculating the amount of ultraviolet irradiation needed to provide air disinfection equivalent to the cubic feet of air per minute for sanitary ventilation indicated by formula (2), Table I and Appendix Fig. A17. This total ultraviolet irradiation, expressed as foot-milliwatts, is the product of the cubic feet of air needed in a room, by the unit lethal intensity (cfmr x 5). Since the equivalent air changes must, however, be obtained almost solely from the irradiated upper air, its volume (uav) times the average intensity (i) required there must equal the total ultraviolet irradiation or,

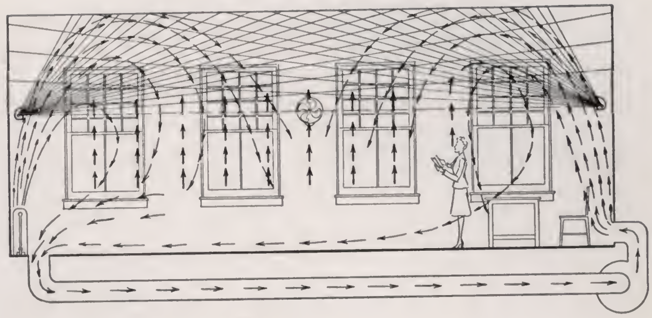
$$(3) \qquad \text{uav} \times i = \text{cfmr} \times 5$$
$$i = \frac{\text{cfmr} \times 5}{\text{uav}}$$

Fig. A18 in the Appendix was prepared from this formula and Table II samples its application to the conditions represented at the lower right of Table I, by assuming the upper air volume to be one-quarter that of the room volume.

Table II

Average Ultraviolet Intensities (milliwatts per sq. ft.) to Provide Sanitary Ventilation (cfmr) in Various Upper Air Volumes (uav).

Upper Air Vol. (cf) (uav)	Sanitary Ventilation (cfmr)				
	800	1600	3200	64,000	128,000
20,000	....	....	....	1.6	3.2
10,000	....	....	1.6	3.2	6.4
5,000	....	....	3.2	6.4	12.8
2,500	....	3.2	6.4	12.8	25.6
2,000	2	4	8	16	32
1,000	4	8	16	32	....
500	8	16	32	....	....



The use of formula (3), and Appendix Fig. A18, may be illustrated by a school room 22′ x 30′ x 12′ seating 25 pupils, and atypical in having an air conditioning system providing 30 cfm of fresh air per pupil as 20% of its circulating capacity. Assume germicidal tubes in the ducts to disinfect the remaining 80% recirculated air. Mechanically supplied fresh and disinfected air to the room then amounts to a total of 3750 cfm (25 x 30 + 4 x 25 x 30 = 3750).

The room volume is 7900 cubic feet and the total sanitary ventilation requirement from formula (2) and Fig. A17 is 7900 cfmr. From this we may subtract the 3750 cfm already supplied leaving 4150 cfm to be provided by ultraviolet irradiation. The upper air volume available for irradiation by germicidal fixtures mounted 7 feet from the floor or 5 feet from the ceiling is 3300. From formula (3) or Appendix Fig. A18,

$$(3) \quad i = \frac{4150 \times 5}{3300} = \begin{array}{l}\text{6.3 milliwatts per sq. ft.} \\ \text{average ultraviolet intensity.}\end{array}$$

Had the above been a typical school room without forced air circulation the calculation would have been

$$i = \frac{7900 \times 5}{3300} = \begin{array}{l}\text{12 milliwatts per sq. ft.} \\ \text{average ultraviolet intensity.}\end{array}$$

Where, as above, no allowance is made for room leakage or mechanical ventilation by subtraction from the sanitary ventilation (cfmr) of formula (2) and Appendix Fig. A17, the latter may be combined with (3) to define required average intensities directly as

$$(4) \quad i = \frac{500{,}000 \times n^2}{\text{uav} \times v} = \frac{500{,}000 \times n^2}{w^2 \times l^2 \times h \times fc}$$

where w = room width
l = room length
h = room height
and fc = fixture to ceiling distance.

The above typical school room may then be calculated as

$$i = \frac{500{,}000 \times 25 \times 25}{22 \times 22 \times 30 \times 30 \times 12 \times 5} = \begin{array}{c}\text{12 milliwatts} \\ \text{per sq. ft.}\end{array}$$

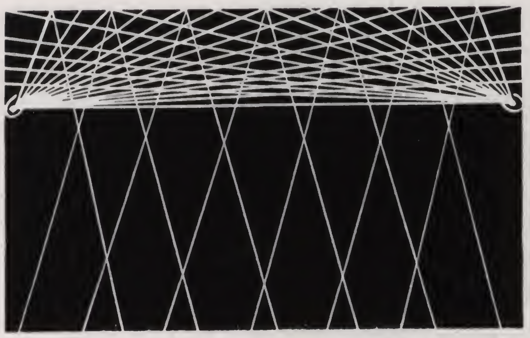
From such calculations and charts the number of germicidal tubes may be determined from the ultraviolet output and spatial distribution characteristics of available fixtures. Tabulated results of such calculations should be supplied by equipment manufacturers.

SECTION III

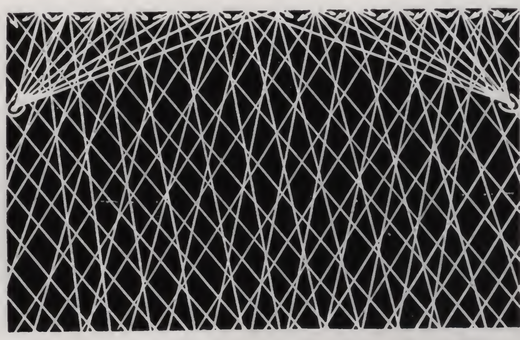
EQUIPMENT

Fixtures for Upper Air Irradiation

Germicidal fixtures must be selected with great care to kill the germs in a room without injuring the people in it. They are projectors whose reflectors must be as carefully shaped from mirror surfaced aluminum or chromium plate as the reflector of a searchlight. Fluorescent lighting fixtures for indirect room illumination and germicidal fixtures for room air disinfection may look alike but they differ in function. The former are to irradiate only the surface of the ceiling, the latter to irradiate only the space just below. Such indirect lighting fixtures project as much light as possible onto a ceiling of maximum light reflectivity to make that surface, in turn, a source of light for the illumination of the lower part of the room. Germicidal fixtures project as much ultraviolet as possible through the space just below a ceiling of minimum ultraviolet reflectivity to make that space, in turn, a source of germ-free air for the sanitary ventilation of the power part of the room.



Germicidal units send as much ultraviolet as possible across the room with as little as possible to the ceiling or down into the room.



Indirect fluorescent lighting units send as much light as possible to the ceiling, for diffuse reflection into the room.

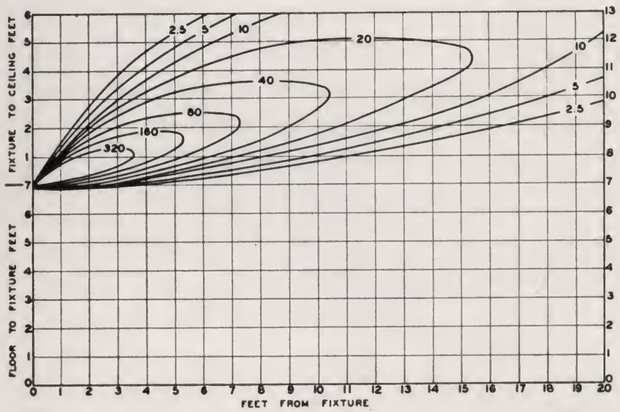
CHOICE OF FIXTURES

The most general problem in the choice and installation of fixtures is that of the low ceiling, less than 10 feet. The low ceiling reduces the volume of upper air available for irradiation. It increases the intensity of the ultraviolet scattered downward to the faces of room occupants by the ceiling's ultraviolet reflectance which cannot be reduced below about 5%. The choice of fixture type is further dependent upon whether there is continuous exposure of room occupants, as in a hospital ward, or only about one-third of the time per day, as in a school room or office.

Two types of fixtures are available, louvered and unlouvered, for use with three sizes of germicidal tubes, 8-, 15- and 30-watt. The choice of fixture and tube is dependent upon the room ceiling height and the possible exposure time; continuous, as in hospitals; or 6–8 hours per day, as in schools or offices.

Louvered Fixtures

Louvered fixtures, Figs. 5, 6, 7, and any of the three tubes, may be used under any condition of ceiling height and exposure except where there may be continuous exposure of people under ceilings 9½ feet or less in height. Then only 15- or 8-watt tubes should be used. With a shorter exposure, one-third as long per day, or higher ceilings, over 9½ feet, or both, 30-watt tubes may be used. Good louvered fixtures, Fig. 5, project 25–35% of the ultraviolet output of the tube in a direction of maximum intensity upward 10–15° from the horizontal. In that direction the intensity should be about six times that of the bare tube. The louvers intercept all energy from the tube itself above an angle about 40° from the horizontal.



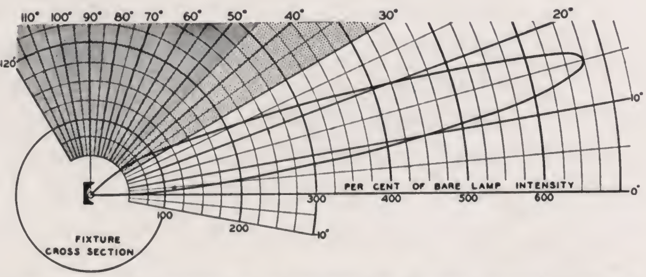


Fig. 5. Spatial distribution of ultraviolet from a typical louvered fixture.

Fig. 6. Isointensity lines of louvered germicidal fixture — milliwatts per sq. ft.

Fig. 7. Typical hospital ward installation of louvered germicidal fixture.

Open or Unlouvered Fixtures

Open or unlouvered fixtures and any of the three tubes, Figs. 8, 9, 10, may be used where there is exposure only about one-third of the time per day, under ceilings 9½ feet or more in height. With lower ceilings *or* continuous exposure, only 15- or 8-watt tubes should be used. With lower ceilings *and* continuous exposure, as in a home bedroom, only 8-watt tubes should be used. Good open fixtures, Fig. 8, project 35–50% of the ultraviolet output of the tube in a direction of maximum intensity upward 20–25° from the horizontal. In that direction the intensity should be about four times that of the bare tube. The upper part of the reflector should intercept all energy from the tube itself above an angle about 70° from the horizontal.

Small Open Fixtures—See Appendix

Small open fixtures with reflectors of comparable quality differ from the larger ones of Figs. 8, 9 and 10 only in their greater spatial output in an upward direction and their lesser intensity in the maximum direction, 2–3 times that of the bare tube. They project 35–50% of the ultraviolet output of the tube in a direction of maximum intensity upward 30–40° from the horizontal. They are subject to the limitations of Table III, their low output in an effective direction (10–25° above the horizontal) and a tendency to an objectionable output below the horizontal. See Appendix Tables A-IX and A-X.

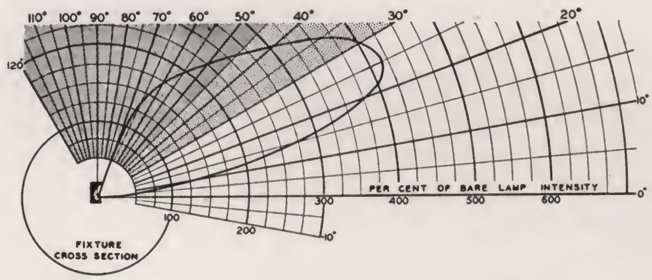


Fig. 8. Spatial distribution of ultraviolet from a typical open fixture.

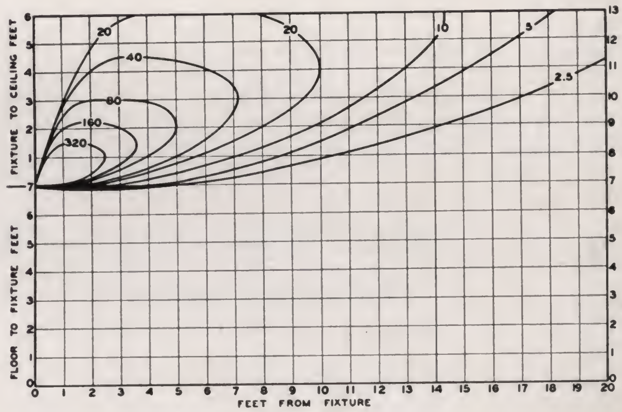


Fig. 9. Isointensity lines of an open fixture — milliwatts per sq. ft.

Fig. 10. Typical school room installation of unlouvered open germicidal fixtures.

Output and Direction

To some extent the lower output of louvered fixtures is compensated by a greater intensity in a more effective direction. The greater output of open fixtures with a lower intensity is possible only because of the greater upward spread of the energy.

High intensity, 3-4 times bare tube, in a high direction, 30—50° above the horizontal, can be very objectionable even under a high ceiling. A high intensity spot may be sufficiently reflected (5—10%) to produce a corresponding area of objectionable intensity in the room below. The absolute intensity projected by any one type of fixture is also directly proportional to the output of the tube used. It is for this reason that 30-watt tubes, for example, cannot be used in open fixtures under low ceilings.

Fixtures — Tubes — Ceilings — Exposures

Table III presents the experience as to various practical combinations of ceilings, exposures, fixtures and tubes (listed by input watt ratings).

Table III

Ceiling Height	Exposure per Day	Louvered Fixtures	Open Fixtures
8—9½ Ft.	Continuous	15- & 8-Watt	8-Watt
8—9½ Ft.	8 Hrs. or Less	30-15-8-Watt	15-8-Watt
9½—12 Ft.	Continuous	30-15-8-Watt	15-8-Watt
9½—12 Ft.	8 Hrs. or Less	30-15-8-Watt	30-15-8-Watt

Number of Fixtures

Of the types of fixtures suggested by Table III the number needed to provide effective intensities can only be determined by reference to the data provided by the fixture manufacturers. They should provide for their fixtures tabulated data on the average ultraviolet intensities the fixtures will provide throughout various upper air spaces, under ceilings of various heights, and when equipped with germicidal tubes of various sizes. These data are most useful when based on the average-throughout-life output of the tubes used.

Fixture Tables — Louvered Fixtures

Such tables have been prepared for the louvered fixture whose spatial output is shown as Fig. 5. Table IV is of intensity factors and Table V applies these factors to the average-through-life rating of a 30-watt germicidal tube, 6.0 ultraviolet watts.

Table IV

Average Ultraviolet Intensity Factors for Louvered Fixture of Figure 5.

	Distance — ft.	10	12	14	16	18	20	22	24
	Areas — sq. ft.	100	150	200	250	325	400	500	600
Tube to Ceiling Feet	5	0.57	0.73	0.87	0.90	0.90	0.87	0.80	0.73
	4	1.40	1.53	1.53	1.43	1.30	1.15	1.02	0.90
	3	3.17	2.78	2.28	1.98	1.65	1.40	1.18	1.02
	2	6.14	4.44	3.32	2.58	2.05	1.67	1.38	1.17
	1	4.00	2.68	1.95	1.47	1.15	0.92	0.75	0.63

Multiply above factors by ultraviolet watts output rating of tube to determine average intensity in various upper air volumes.

Table V

Average Ultraviolet Intensities in Milliwatts per sq. ft.
Produced by 30-watt Germicidal Tube (6 Ultraviolet Watts)
in Louvered Fixture of Figure 5.

	Distance — ft.	10	12	14	16	18	20	22	24
	Areas — sq. ft.	100	150	200	250	325	400	500	600
Tube to Ceiling Feet	5	3.4	4.4	5.2	5.4	5.4	5.2	4.8	4.4
	4	8.4	9.2	9.2	8.6	7.8	6.9	6.1	5.4
	3	19.0	16.7	13.7	11.9	9.9	8.4	7.1	6.1
	2	36.8	26.6	20.0	15.5	12.3	10.0	8.3	7.0
	1	24.0	16.1	11.7	8.8	6.9	5.5	4.5	3.8

Fixture Tables — Open and Unlouvered Fixtures

Since Figs. 5 and 8 represent basic types of good fixtures available from several manufacturers, Tables VI and VII have also been prepared for the open, unlouvered fixture of Fig. 8.

Table VI

Average Ultraviolet Intensity Factors for Open Fixture of Figure 8.

Distance — ft. Areas — sq. ft.		10 100	12 150	14 200	16 250	18 325	20 400	22 500	24 600
Tube to Ceiling Feet	5	3.60	3.03	2.53	2.12	1.77	1.50	1.28	1.10
	4	4.67	3.70	2.93	2.35	1.94	1.60	1.35	1.13
	3	7.02	5.07	3.60	2.80	2.30	1.85	1.55	1.30
	2	9.73	5.98	4.20	3.47	2.68	2.13	1.77	1.46
	1	5.34	3.42	2.40	1.78	1.36	1.08	0.88	0.73

Multiply above factors by ultraviolet watts output rating of tube to determine average intensity in various upper air volumes.

Table VII

**Average Ultraviolet Intensities in Milliwatts per sq. ft.
Produced by 30-watt Germicidal Tube (6 Ultraviolet Watts)
in Open Fixture of Figure 8.**

Distance — ft. Areas — sq. ft.		10 100	12 150	14 200	16 250	18 325	20 400	22 500	24 600
Tube to Ceiling Feet	5	21.6	18.2	15.2	12.7	10.6	9.0	7.7	6.6
	4	28.0	22.2	17.6	14.1	11.6	9.6	8.1	6.8
	3	42.1	30.4	21.6	16.8	13.8	11.2	9.3	7.8
	2	58.4	36.9	25.4	20.8	16.1	12.8	10.6	8.8
	1	32.0	20.5	14.4	10.7	8.2	6.5	5.3	4.4

Tubes of Other Sizes

The use of general factors in Tables IV and VI permits calculation of the intensities provided by tubes of any size in similar or identical fixtures. Or, the intensities provided by other tubes may be calculated from Table V and VII by direct proportion between the tube output ratings. For example the values for 15-watt tubes in an open fixture may be calculated from Table VII by multiplying by .44 (3.1/72). For an 8-watt in a small fixture providing the same spatial distribution, Fig. 8, the factor would be .24 (1.7/7.2).

Manufacturers' Data

Manufacturers of germicidal fixtures should always publish such spatial distribution charts as Figs. 5 and 8 to permit visual appraisal of their units. They should also publish such installation data as Tables III, V and VII. The spatial distribution charts are essential to any appraisal and may be compared with Figs. 5 and 8 of this bulletin, in the absence of such tables as V and VII.

SECTION IV

DESIGN AND INSTALLATION—SPECIAL CONDITIONS

Installation Engineering

The specification of any germicidal installation is based on:

Room dimensions.

Occupancy—maximum probable.

Ventilation—fresh air already available and additional needed.

Upper air—fixture-to-ceiling distance.

Use—hours per day.

Ceiling reflectance.

Nature of use—hospital, school, office, etc.

When not adequately covered by tabulated data from equipment manufacturers the above may be used to calculate an installation design as follows:

From the dimensions and occupancy calculate the total sanitary ventilation needed in the room, as cubic feet per minute (cfmr) of fresh air or equivalent disinfected air by Formula (2) or Appendix Fig. A17. Subtract the fresh air (if any) already available by ventilation (make-up air only—not recirculated air—usually negligible). From the upper air volume (uav) (floor area times fixture-to-ceiling distance) and the equivalent disinfected air (cfmr) needed calculate the average ultraviolet intensity needed throughout the upper air by Formula 3 or Appendix A18. From the ceiling height and the hours use per day (continuous in hospital wards—8 hours or less in schools) select the type of fixture (louvered or open) and the size of germicidal tube (8-, 15- or 30-watt) by Table III. From manufacturers data, such as Tables V and VII, determine the number of fixtures required.

It is expected that manufacturers of fixtures will eventually supply all of the above in tabular form for the more important and typical conditions. Such step-by-step calculations as outlined above would then only be necessary in unusual cases.

Special Cases-Humidity-Spring and Tropical

The humidity of spring weather and the tropics may render a germicidal installation so relatively ineffective as to necessitate special attention to the natural ventilation especially during spring weather when, in the case of hospitals for example, respiratory diseases are still prevalent, the air heating and convection circulation is at a minimum and windows are still kept closed.

In locations where the relative humidity is generally in the 70—90% range there should be considerable increases in the number of germicidal tubes used. Because of the increased number, the fixtures should be low angle types, louvered reflectors under low ceilings, to minimize the reflection of ultraviolet into lower parts of the room.

Duct Installation

In places where there is 1000, or more, cubic feet of air per occupant (upper left of Table I and Appendix Fig. A17 and unusual provision for recirculation of air it may be practical to provide some or all of the needed sanitary ventilation by germicidal tubes in the air ducts. Such installations are discussed in a later section of this bulletin.

Ceiling Reflectance — A.M.A. Exposure Limits

The ultraviolet reflectance of ceilings and walls must always be considered early in the design of an upper air installation of germicidal tubes. The Council on Physical Medicine and Rehabilitation of the A.M.A. has set limits of exposure tolerance for various exposure times. Where there may be continuous exposure, as in hospital wards and dormitories, the ultraviolet intensity on faces, must not exceed 0.1 microwatt per sq. cm. (0.1 milliwatts per sq. ft). Where there may be less than seven hours total exposure per day the intensity must not exceed 0.5 microwatts per sq. cm. (0.5 milliwatts per sq. ft.). It is easily possible to meet these specifications by precaution. See Appendix.

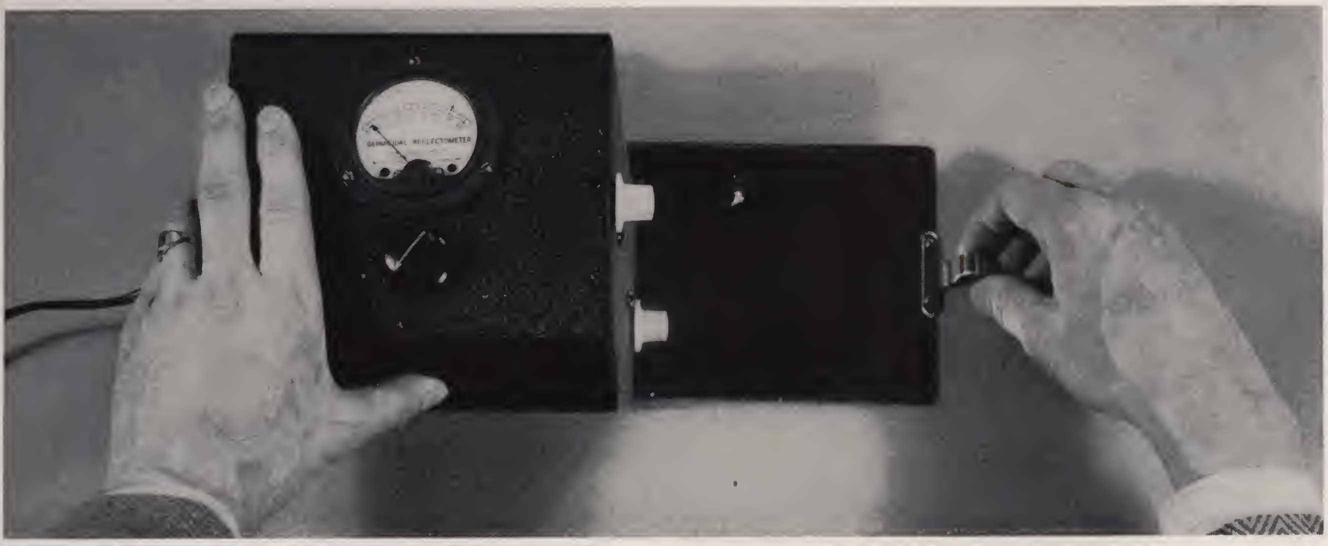


Fig. 11. Germicidal Reflectometer.

Reflectance and Intensity Meters

Precision meters are available for measuring the percentage reflectance of wall and reflector surfaces and ultraviolet intensities in irradiated spaces and on irradiated surfaces. The reflectance meter, Fig. 11, should be used wherever there is the slightest doubt as to the ceiling reflectance.

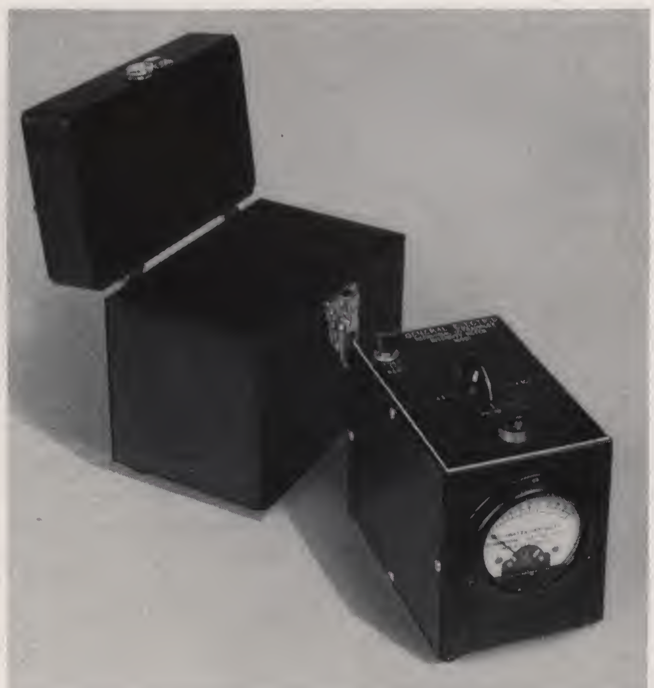
The intensity meter, Fig. 12, should be used wherever there is the slightest doubt as to the ultraviolet intensities either in the irradiated upper air of a room or on the faces of people in the room. It measures intensities ranging from those tolerated continuously on an infant's face (0.1 milliwatt per sq. ft.) to those six feet from the fixtures of Figs. 5, 6 and 7 (100 milliwatts per sq. ft.).

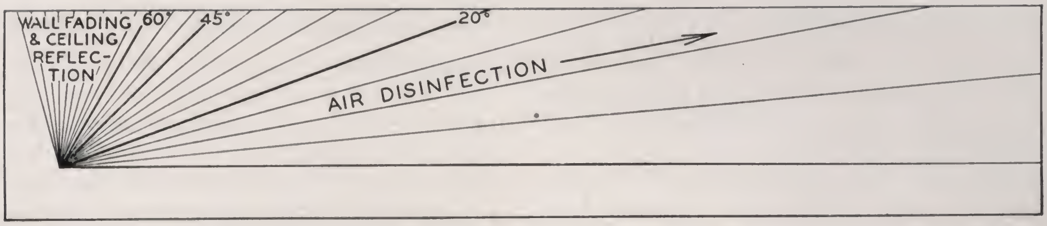
Ultraviolet reflectance is uniquely a characteristic of the solid fillers and pigment materials rather than the vehicles used in wall paints and finishes. Oil vehicle paints generally have low, 5—10% reflectances, regardless of the fillers and pigments, because of the absorption of the oil. On the other hand, a few paints using synthetic plastic vehicles of low ultraviolet absorption may have high, 15—40% reflectances. Acoustic ceilings of perforated and factory painted metal seem to have a low reflectance. But acoustic ceilings, of the wallboard type, surfaced with gypsum products, or made entirely of them, may have reflectances as high as 50%. The chemically similar "white-coat" plaster finish always has such a high reflectance, making effective upper air ultraviolet irradiation impractical where there may be exposures of personnel for more than two or three hours per day, regardless of ceiling height. Such plastered ceilings should be oil painted. The acoustic ceiling should be sized with one or two light coats of a casein wall size or filler which will reduce its reflectance with little or no effect on its color and acoustic properties.

Ultraviolet "Hot-spots"

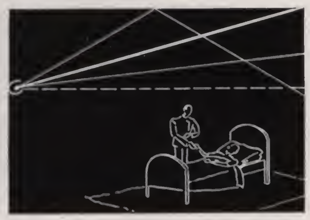
Face irritation seldom results from a 5—10% reflectance of the average ceiling intensity of 5—20 milliwatts reduced inversely as the distance from the ceiling. It results from exposure in very localized spots of high intensity corresponding to high intensity areas on the ceiling where the intensities may be as high as 200 milliwatts per sq. ft. near such an open and high angle fixture as that of Fig. 9 under a 9-foot ceiling. Since such hot spots at face level can be built

Fig. 12. Germicidal Ultraviolet Intensity Meter.





up by reflection from several adjacent high intensity spots on the ceiling this must be allowed for in the choice fixture sizes and locations. Fixed positions, as for example, infant bassinets, may often influence the choice of fixture positions, especially under low ceilings—even when small units are used. A preliminary check will often avoid misplacement of equipment.



Fixture Placement

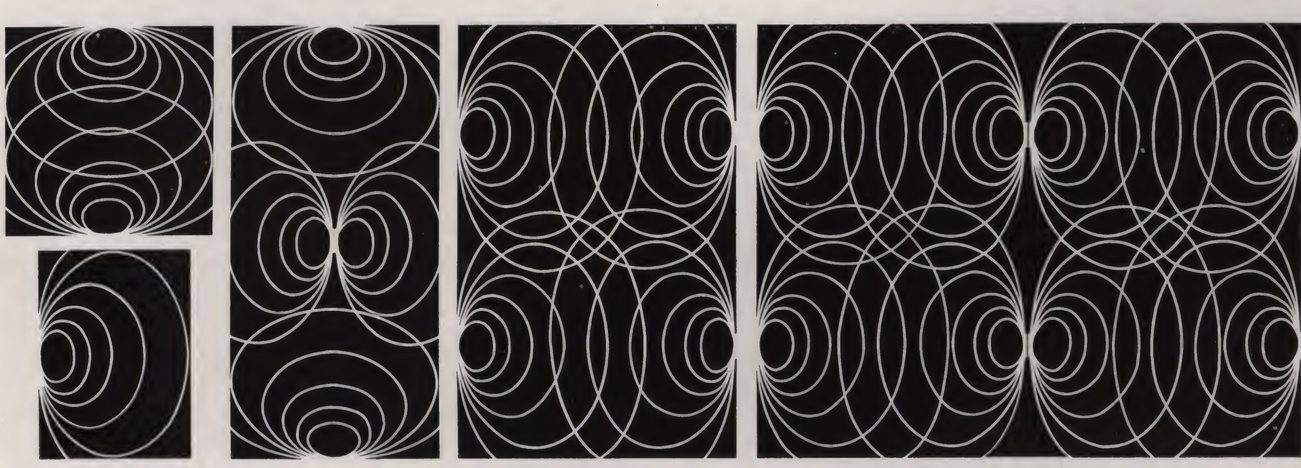
Unlike the case with light for illumination, germicidal ultraviolet, in air, from opposite directions is additive in its germicidal effectiveness. The ideal locations for two fixtures in a room are on the opposite sides to provide high intensities near one fixture additive to low intensities from the other.

Fixtures should be distributed on the side walls and ceiling to provide as uniform upper air irradiation as possible, remembering that the individual units are effective over the square areas indicated by such tables as V and VII, depending upon the type of fixture and the fixture to ceiling distance. This means that even in a small room two 15-watt units on opposite walls are better than a single 30-watt and that in rooms of a length double the width, two fixtures should always be used, centered on the end walls. In rooms wider than 30 feet, and especially those with ceilings less than 10 feet, it is necessary to install some of the fixtures out in the central parts of the rooms by mounting wall-type units on columns, or by suspending from the ceiling pairs of wall units back-to-back.

Fixture Mounting Suggestions

While each fixture must be attached to the wall or ceiling in the ways suggested by the manufacturer they should be kept away from room corners a distance at least double that to the ceiling. Ceiling or column mounted fixtures should be as low as possible, usually one foot higher than is practical on the side walls.

While many fixtures are equipped for "pin-up" mounting and extension cord connections to convenience outlets they should not be used for permanent installations. Surface wiring by metal ducts may be used in finished buildings to provide switching and circuits separate from the lighting circuits. In institutional installations time switches may be used to advantage to insure operation of the germicidal tubes during room use and then only. Since the germicidal tubes are generally operated whenever rooms are used it is a useful expedient, especially in older buildings, to connect the fixtures to the circuits serving the convenience outlets (if there are no clocks on them). A time switch can then be installed at the distribution panel to control all germicidal tubes on a circuit which may serve several rooms, floors or sections of a building.

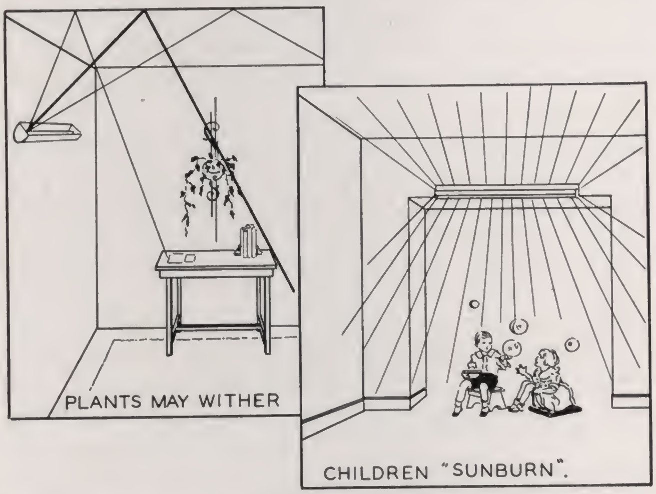


Caution-Fading-Plants-Children

Germicidal ultraviolet, like the sun's ultraviolet, will fade some wall paints and papers and drapery fabrics, especially where their upper ends extend into the directly irradiated upper parts of a room. Although there has been little such trouble, the possibility should always be anticipated, especially in offices and homes.

As is well known, plants are more sensitive than humans to most of their environment. Ultraviolet intensities tolerated indefinitely on an infant's face wilt the leaves and eventually kill such plants as ivy, unless they are protected, for example, by curtains inside a window shelf.

Fixtures designed for hospital use to provide a downward barrier of ultraviolet across door openings and the front of hospital cubicles should not be installed in places where infants or children may expose their eyes and faces for indefinite periods to the direct radiation from the bare tube.



Local Rules on Explosion-proof Equipment

Local rules as to the use of explosion-proof switches and lamps, below the 5–7-foot level, apply also to the switching of germicidal tubes and sometimes to the tubes themselves when used for floor and lower air irradiation. Although germicidal fixtures cannot practically be enclosed as can filament lamps, it is believed that there is little actual need for such enclosure. The essential requirement of such regulations can usually be met by placing the starting device outside the operating room or by using manual starting of the lower side wall and portable units with compact types of hand-operated safety switches which are entirely practical here because of the very low currents and voltages involved.

The slimline G36T6 tube with its high ultraviolet output and its starting without a starting device and induced high voltages may be used to advantage for lower air and floor irradiation. See Section VI and the Appendix for further detail on it.

Face and Eye Irritation

Germicidal ultraviolet, like the sun's ultraviolet will irritate (sunburn) the face and eyes in various exposure times, dependent entirely upon the average exposure intensity. It is very important to note that the time is as important as the intensity and that in practice bare germicidal tubes and unlouvered fixtures may be used in many places where people may not be exposed very long per day. In such places the ultraviolet sources may be so placed that no one—children especially—can get near enough (less than the length of the tube or fixture) for a very high intensity exposure even for a short time. The more important intensities and exposure times are tabulated in the Appendix.

Since hospital conditions need the highest intensity installations permitted by ceiling reflectance and height, new installations should always be operated for at least 24 hours, at only 8 hours per day, or continuously if the room is unoccupied. After that the intensity at the infant face levels should be checked to see that the intensity on the faces of infants is not over the 0.1 milliwatt per square foot, or 0.1 microwatt per square centimeter limit set by the Council on Physical Medicine and Rehabilitation of the A.M.A. (Experience has indicated that adult faces have a tolerance several times that of infant faces.) If found too high, adjustment of the fixture if possible, repainting or sizing of the ceiling, or removal of fixtures are obvious means of correction.

Ozone — A.M.A. Limits

During the first 100 hours of operation some germicidal tubes produce noticeable amounts of ozone, how noticeable depending upon the humidity of the air and the amount of ordinary ventilation in the room. An odor of ozone in a room where there are germicidal tubes is evidence of air circulation in the room but little ventilation, because ozone is produced only within a few inches of the tubes by traces of ultraviolet of much shorter wavelength (1849A) than the germicidal.

Excessive ozone is nearly always an indication of inadequate ventilation by any standards of comfort and health. In any case the ozone-producing quality of such tubes is reduced to less than half during the first few days of use and most of this reduction can be secured by operating a new installation for about 24 hours while the room is unoccupied. In cases of persistent ozone look to the ventilation.

The Council on Physical Medicine and Rehabilitation of the A.M.A. has set a limit of one part per ten million of ozone in the air of occupied rooms. This concentration, or less, is believed of no value for air disinfection but may have some effect in odor control.

Odor Reduction

Experience indicates that a normal germicidal tube installation is of value for odor control. The effect is easily observed but difficult to measure. The ultraviolet may promote the oxidation of odorous substances, usually of an unstable chemical nature anyhow, either directly or by way of the very active form of oxygen present in the air from the formation and decomposition of ozone. The ozone itself also doubtless has a desensitizing action on the nose analogous to the effect of certain sound and light waves, or of certain flavors on the corresponding senses. It is interesting to note that this odor suppression seems to be effective under conditions where the ozone itself is barely if at all detectable.

Blue Light from Germicidal Tubes

Germicidal tubes are low efficiency sources of light (3—4 lumens per watt) which gives an appearance of bright moonlight in the usual upper-air installation. While it has not proven objectionable in the unusual environments of hospital wards and navy barracks it has been objectionable in home sick rooms and bedrooms. It has been thought an asset as night lighting in institutional dormitories.

This light has, however, interfered with the showing of colored motion pictures. Fortunately modern theatres may have unusual air conditioning systems. Germicidal tubes in the air ducts to disinfect all the recirculated air may provide one-half, or more, of the needed sanitary ventilation. Enough upper air irradiation to provide the rest often can be used without objectionable light.

Operation

Germicidal tubes should be operated continuously all the time people are in the room but they serve little purpose before or 15 minutes after such periods. Any installation which will disinfect the air of a room as rapidly as it is contaminated by the people in it will clean up any residual contamination very quickly indeed as soon as the room is vacated. Continuous operation is usual in hospitals, time switches or entirely centralized controls are recommended in schools, and any switching method independent of individual whims may be used in offices and industrial installations. Germicidal tubes should be on circuits entirely independent of the lighting circuits.

Tube Replacement

General Electric germicidal tubes are rated at their output after 100 hours operation but the fixture recommendations in this guide are based on the average output through life rather than the 100-hour rating. Group replacement at intervals of three-fourths the rated life is recommended for industrial and some institutional installations, an alternative method is individual replacement of all lamps that depreciate below 70% of the 100-hour rating, as indicated by available germicidal output meters.

Output Wattmeter

A germicidal output meter is available for measuring directly the output of 15- and 30-watt tubes in total ultraviolet watts. An adaptor permits a similar direct reading on slimline G36T6 tubes. This meter is essential to proper tube cleaning and replacement.

Fig. 13. Germicidal Wattmeter.

Maintenance

Maintenance of a germicidal installation should be on a much more definite and arbitrary basis than is usual with lighting installations because the user has no visible indication of the ultraviolet output of the germicidal lamp nor any direct evidence of air disinfection. Lamps and fixtures should be cleaned every two to four weeks depending upon local conditions, and in some places every week. While special aluminum and chromium cleaning materials are best for the reflectors most any of the usual glass cleaning compounds may be used on the germicidal tube and reflector so long as no materials containing oils or waxes are used. Cleaning powders that do not scratch are good. Only perfectly clean wiping cloths should be used.

Caution — Caution Notices

Tube and reflector cleaning and tube replacement should be intrusted only to those who will uniformly observe the essential precaution of never exposing the face and eyes to an operating tube while working on it or the reflector.

The reflectors of all fixtures should carry a caution notice identical in type size and face with the following. It should be placed just above the center of the tubes—the bottom of PROTECT EYES exactly in line with the top of the tube.

TURN OFF LAMP

PROTECT EYES

WHILE WORKING NEAR IT

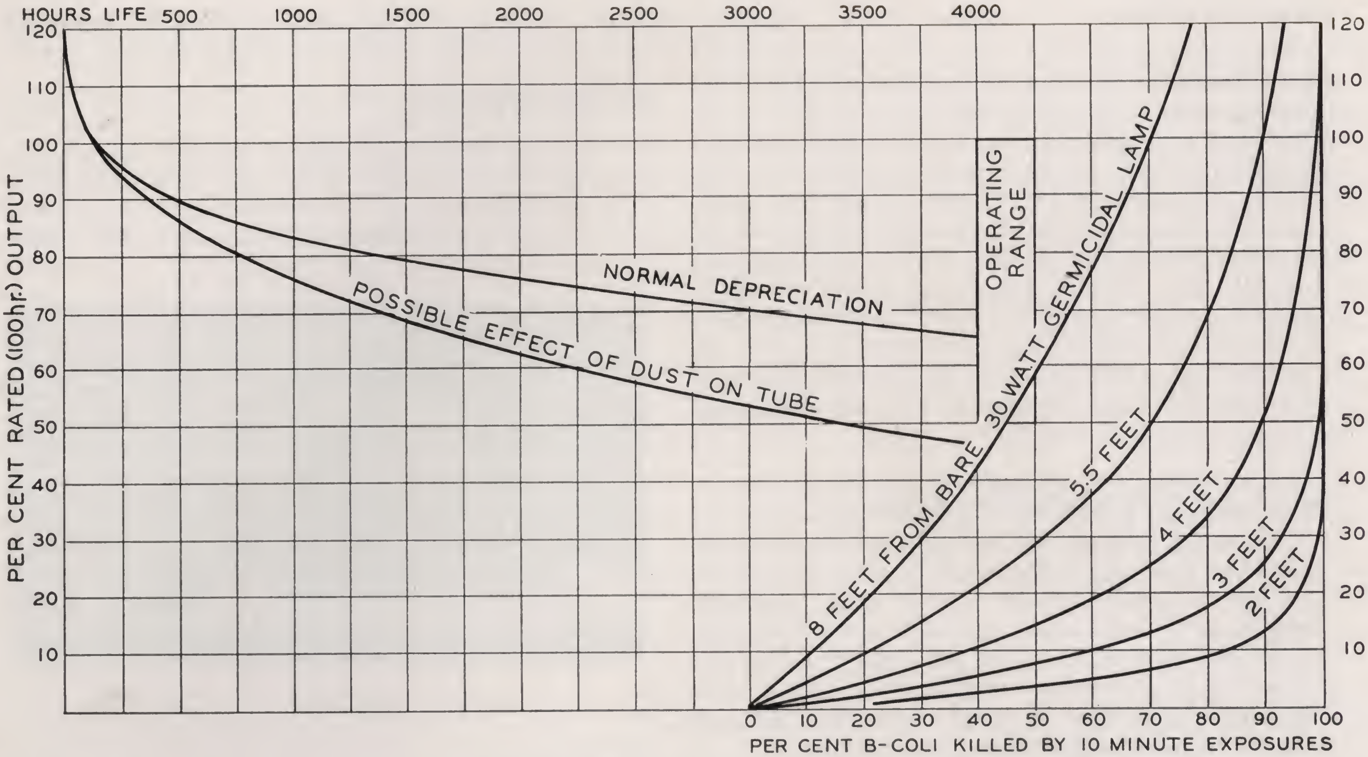


Fig. 14. Effect of dust and depreciation on the ultraviolet output and effectiveness of a germicidal tube.

Depreciation—Life and Output Control

In common with fluorescent lamps germicidal tubes depreciate rapidly during the first 100 hours of operation and are given an initial rating as of the end of that time. The depreciation characteristic of 15- and 30-watt germicidal tubes in practically continuous operation is shown above. Intermittent operation, intervals of 3 hours or less, will increase the rate of depreciation and reduce the average life to 2500 hours or less.

Germicidal Effectiveness

The bactericidal effectiveness of ultraviolet energy, like the illumination effectiveness of visible energy, does not vary at all directly in proportion to the intensity of the energy. It is entirely practical to install germicidal tubes on such a basis that the final depreciation due to full life operation plus the effect of dirt, which may total 50 per cent of the 100 hour initial rating, only decreases the germicidal effect by 1 per cent in the case of the deluxe installation based on a 99.99 per cent upper air disinfection or by 10 per cent in the usual installation, based on a 99 per cent upper air disinfection.

Expressed in another way, the intent in the germicidal treatment of air, for example, is to provide an intensity which will insure a practically complete bacteria kill in a sufficiently short time and one minute will serve for an example. A 50 per cent decrease in intensity may double this time for a satisfactory kill but it is still a very effective rate of bacteria disposal compared with anything possible by ordinary ventilation.

Expressed in yet another way, for those familiar with illumination data, the ultraviolet intensities recommended for air and surface disinfection are comparable with 1000 and 500 footcandle recommendations for illumination, and the possibility of 50 per cent decreases from those levels. Illumination practice started with minimum useful intensities and is slowly working up to natural outdoor intensities while ultraviolet air disinfection practice is starting with an attempt to duplicate natural conditions of pure air and will doubtless slowly work down to some adequate lower level.

Expressed graphically, on ordinary coordinates, the energy intensities typical of depreciated and soiled germicidal tubes in relatively continuous operation and their relationship to the germicidal effectiveness is shown in Fig. 14.

SECTION V
TYPICAL AND SPECIAL INSTALLATIONS

Air Sanitation or sanitary ventilation has been accepted as of value in hospitals by the Council on Physical Medicine and Rehabilitation. The American Hospital Association has assigned to a special committee responsibility for appraising such methods of air disinfection as ventilation and ultraviolet irradiation.

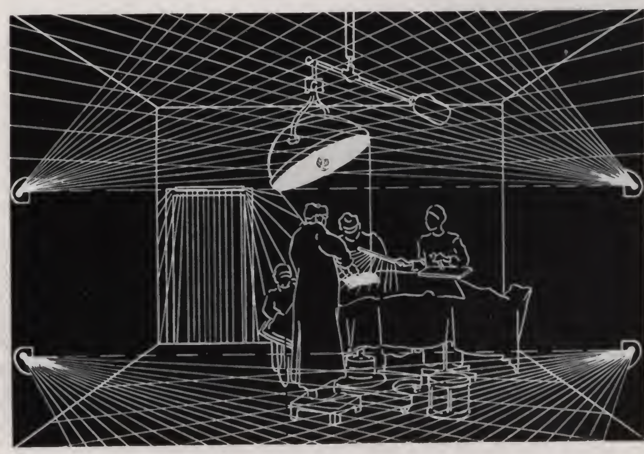
Hospital Operating Room

The first acceptance of Ultraviolet Air Sanitation in hospitals was based on its use in operating rooms. There it supplemented other highly developed aseptic techniques that did not solve the problem of contaminated air. The problem in the surgery is primarily that of protecting tissues exposed during operation. Debilitated tissues exposed during long operations may be contaminated by many pus forming and fever producing organisms not ordinarily a hazard. Even mold spores may sometimes cause trouble. The problem is especially serious in brain surgery and thoracoplasty operations where the tissues may be exposed for hours and where there may be little opportunity to treat subsequent complications.

Although the aseptic practice in the operating room is of necessity superior to that in any other part of a hospital, air and floor irradiation can still further improve the practice. The earlier and obvious method was by direct irradiation of all the air, the nurses, the patient and the surgeon from bare bactericidal tubes attached to the ceiling or to the operating lamp. But effective ultraviolet intensities were found to necessitate complete hand and arm protection of the whole operating team. These objectionable precautions can be avoided and as satisfactory results secured by intensive irradiation of the air above the 6½—7-foot level, and below the 2½—3-foot level, as already specified for a normal installation, supplemented by irradiation of the incision with a hand-held and directed source of ultraviolet.

Double the normal upper air installation is recommended, with the addition of floor and lower air irradiation from a 30—36-inch level using the same number of 30-watt units as for the upper air. The same type fixtures can usually be used for both purposes, inverted for the floor irradiation. An added precaution is a strong downward screen or barrier of ultraviolet across the doors, as across infant cubicles, from fixtures placed over the doors. Either movable baffles on the fixtures or additional bare germicidal lamps on the ceiling near its center, on a separate electrical circuit, may provide for wall and additional floor air and floor irradiation between uses of the operating room. Such fixtures will also provide the direct irradiation of the room and the operation sometimes desirable in thoracoplasty and brain surgery.

Since the germicidal tubes in operating rooms are operated continuously through the operating hours they may be on wall switches above the explosion hazard zone (over 6—7 feet from the floor) or outside the room. Where floor irradiation is used all the tube starting and operating equipment must be entirely outside the room or over 6—7 feet from the floor if in it.



Contagious Diseases in the General Hospital

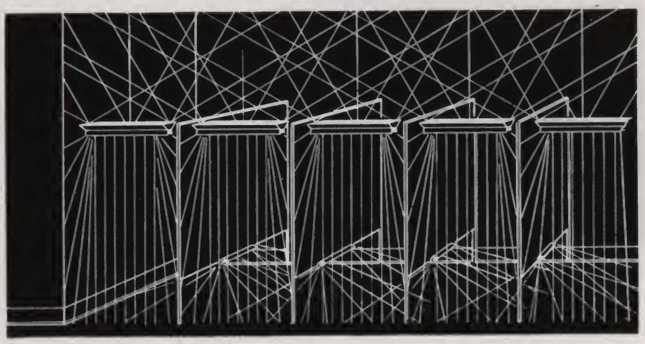
There is increasing emphasis on the basic fallacy of the old idea of entirely separate hospitals for the care of communicable diseases in view of the effectiveness of modern techniques of isolation possible by air disinfection and controlled ventilation. By means of germicidal lamps for general air disinfection, by controlled air circulation and pressure, and by the use of high intensity germicidal barriers of ultraviolet, it is entirely practical to use the general hospital for the housing of even highly contagious respiratory diseases. It is entirely practical, on the other hand, to use already established contagious disease or isolation hospitals for general cases, especially in times of emergency.

Infant Wards and Cubicles

While contagious disease hospitals or wards are the most natural places for germicidal lamps the most universal need is doubtless in the infant wards, especially the premature. Here the ideal method of protecting infants from each other is by the use of cubicle partitions from the 7-foot level down nearly to the floor, with the minimum of floor clearance needed for floor cleaning, with a germicidal tube across the upper front of each cubicle. It should provide, along with high intensity upper air irradiation, a downward curtain or barrier of ultraviolet kept carefully away from the patients' faces. Fifteen-watt General Electric germicidal tubes are adequate in length and ultraviolet output for such use.

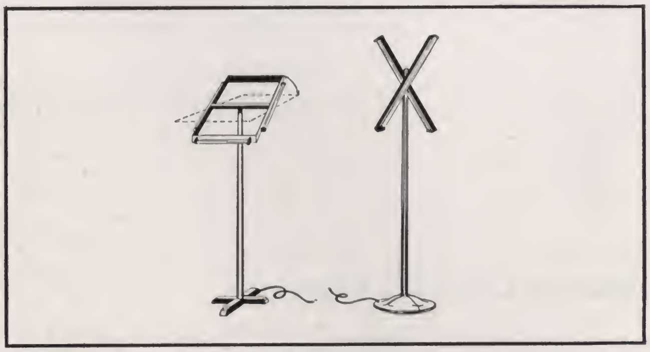
Where premature wards are maintained at a relative humidity of 70—80% two or three times the usual upper air ultraviolet intensities should be provided, or as much as the ceiling height and reflectance will permit, with louvered fixtures.

The deluxe infant cubicle may also be equipped with 15- or 8-watt germicidal tubes permanently built into the lower edges of the cubicle partitions at 12—18 inches from the floor to provide irradiation of the floor dust and lower air in addition to the essential upper air irradiation.



Portable Disinfector

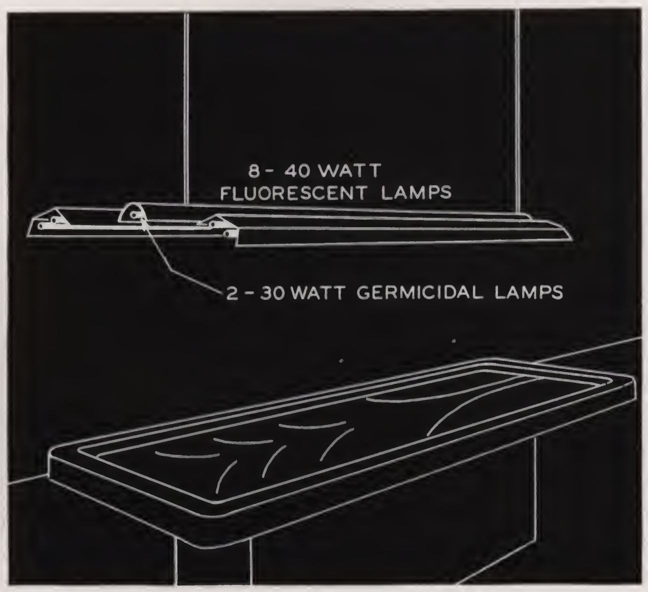
A portable irradiator for the disinfection of the air, walls and floor of operating and ward rooms between transient occupancies is suggested as a supplement, not a substitute, for the usual room cleaning. Such a device should have an ultraviolet output sufficient to disinfect the remote corner wall surfaces of the larger semi-private rooms to a theoretical 99% in 10 minutes and should be operated in such rooms 20 to 30 minutes. Two 30- or four 15-watt germicidal tubes at about 35° from the vertical will provide a sufficiently uniform irradiation of ceiling and floor centers and the side walls.



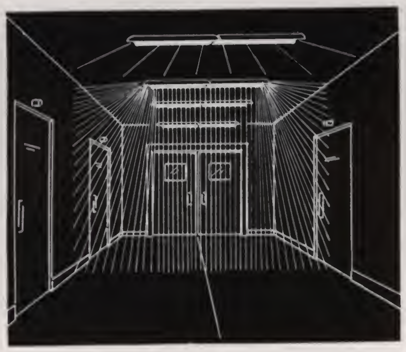
A similar uniformity of wall exposure may also be secured with various arrangements of stationary lamps operated by a delayed opening time switch.

Autopsy Rooms

Germicidal tubes may be of unique value in autopsy rooms where air-carried tuberculous infection is common. Two 30-watt tubes end-to-end in slender



concentrating reflectors should be hung over the operating table. Such an installation may well be combined with fluorescent supplemented with filament lamps for autopsy illumination as is suggested in the sketch above. The germicidal tubes can to advantage be combined with a lighting fixture hung at 6½–7 feet from the floor. The ultraviolet intensity is such as to necessitate the wearing of transparent face and head shields. In any case, the usual gloves and nose-mouth masks should still be worn. Where there may be an unusual infection hazard or very long hours of close range work with low mounted germicidal tubes the transparent face shield should be worn to guard against face irritation from reflected ultraviolet and to add to the bacterial effectiveness of the cloth face mask.



Corridors

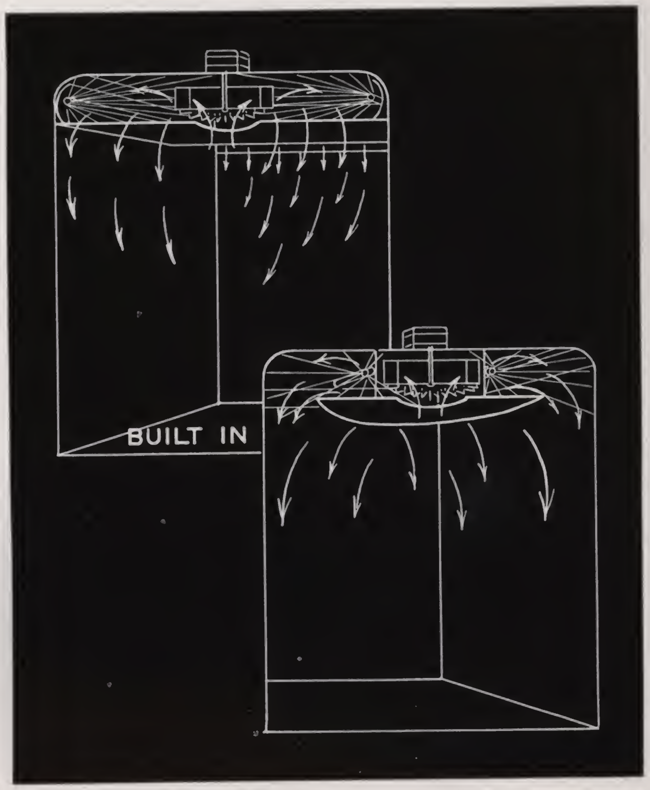
Where germicidal tubes may not have been used in rooms because of very low ceilings or highly reflective ceilings nor over the doors intense barriers across the corridors may be used to advantage to prevent the free corridor circulation of infection known to be characteristic of all hospitals. Single 30-watt germicidal lamps preferably in cylindrical parabolic reflectors are adequate for corridors 5–6 feet wide and for wider corridors use additional units end-to-end. The number of such corridor barriers required depends upon the number of unequipped rooms opening upon it and should be such as to intercept all possible air currents between rooms.

In some places standard side wall units inverted on the end walls of corridors, or inverted back-to-back and mounted on the ceiling, may be used to advantage.

Concentrating fixtures are best for this purpose to minimize the intensity below the unit.

Elevators

The operators of hospital elevators may be provided with sanitary ventilation by the use of germicidal tubes and an entirely practical local air circulation of 300 to 500 cubic feet per minute. Ordinary upper air irradiation is not suggested because of the low ceilings and the difficulty of protecting the operator from reflected ultraviolet. Specially designed commercial equipment such as that sketched above is available and recommended as able to supply a 60–120 air change equivalent for sanitary ventilation.



Service Rooms

Germicidal tubes may properly be used in nearly all service rooms of the hospital, such as those for the preparation of dressings and operating instruments, the kitchens, laboratories and laundries. In most cases direct irradiation of the work may be provided as in the autopsy rooms, with whatever hand and face protection, if any, the time of exposure may require.

Air disinfection is believed of special value wherever there may be handling of the linen from tuberculous patients or from any contagious disease wards.

So-called terminal sterilization of formula foods, surgical instruments and dressings, like the pasteurization of milk, is no justification for neglect of basic sanitation before final treatment. Air disinfection is an obvious supplement to filtration which removes only the coarser contaminated dust from air.

It should be again emphasized in this connection that ultraviolet air disinfection is a general rather than specific sanitary precaution comparable with the detergent cleaning of the surfaces of utensils. It supplements but does not replace such basic sanitary measures.

Hospital Air Ducts

Germicidal tubes may be of value in those few hospitals permitting some recirculation in heating or ventilating ducts, as they make it possible to insure a recirculated air equivalent to the outside or make-up air. When further experience has completely proven the practicality of such a disinfection of recirculated air in hospitals a considerable saving in heating cost may be possible. It should be noted here that outdoor air is usually considered sufficiently free of disease-producing germs for hospital use, even though it may be greatly contaminated with dirt and fungi not completely removable by practical dust filters.

The generalities of germicidal duct installations discussed later apply directly to the hospital. Only the special problems of inflammable vapors and high humidity may call for care in placing the lamps to minimize both.

Calculation of Installations

The data on typical germicidal installations will be found in equipment manufacturers' catalogs but the methods of calculating them are here reviewed by typical examples.

Example — Large Hospital Ward

Assume an unusual hospital ward bedding 24 patients in a 24 x 72 x 9-foot room having an oil painted ceiling and a minimum of ventilation. Since the ceiling is low we must crowd the fixture down to 6½ feet from the floor leaving a 2½-foot distance from the fixture to the ceiling. Since the sanitary ventilation by fresh air is negligible in this case Formula (4) can be used to directly calculate the average upper air intensity needed for air disinfection (assuming four nurses in the ward).

$$i = \frac{500{,}000\ n^2}{w^2 \times l^2 \times h \times fc} = \frac{500{,}000 \times 28 \times 28}{24 \times 24 \times 72 \times 72 \times 9 \times 2.5} = 5.8$$

Double this intensity to 11.6 because contamination and the need for air sanitation is considerably greater in hospitals than in other places. Refer to Table III where only 15- and 8-watt tubes in louvered fixtures are suggested for continuous use under less than 9½-foot ceilings. Treat the room as three 24 x 24-foot areas and consult Table V for the average intensity 7 milliwatts per sq. ft., provided through a 24 x 24 x 2½-foot upper air volume. Lacking such a table on similar 15-watt fixtures multiply by .43 for the intensity of 3 milliwatts per sq. ft. provided by them. Four such fixtures are needed for each 24 x 24-foot area or a total of 10 for the room. They should be mounted on the long walls on 12—14-foot centers, either symmetrically or alternately depending upon the location of windows, columns, etc. Had the ceiling been 10 feet or higher one-half as many 30-watt units could have been used, Table V.

Example — Small Hospital Ward

Assume the usual four-bed hospital room, 18 x 20 x 10 feet, painted ceiling, negligible ventilation possible use for respiratory cases. The needed ultraviolet intensity for four patients and a nurse would be

$$i = \frac{500{,}000 \times 5 \times 5}{18 \times 18 \times 20 \times 20 \times 10 \times 3} = 3.2$$

Double this and refer to Table III where louvered 30- or 15-watt fixtures are suggested and to Table V which suggests that a 30-watt fixture is unnecessarily large and a single 15-watt unit adequate (.43 x 11).

Example — Hospital Infant Ward

Assume a 12 x 16 x 10-foot infant nursery for eight cribs and a nurse

$$i = \frac{500{,}000 \times 9 \times 9}{12 \times 12 \times 16 \times 16 \times 10 \times 3} = 7.8$$

Double this and refer to Tables III and V where a 30-watt louvered fixture will be found adequate.

Example — School Room

The unventilated school room of our previous example needed an average intensity of 12 milliwatts per sq. ft. with a fixture-to-ceiling distance of 5 feet and an area of 660 square feet. Table III suggests that an open fixture may be used. From Table VII one 30-watt open fixture would provide an average of 10 milliwatts per sq. ft. throughout a square upper air area about one-half the school room area and less than the school room width in size. So two such units would be required.

SECTION VI

DUCT AIR DISINFECTION

Although it is easily possible to disinfect all the air handled by a duct to a bacterial equivalence to outside air, and thereby remove one of the objections to recirculated air, the limited sanitary value of practical duct capacities was emphasized in Section I. There still remain many cases where duct air disinfection is desirable, where the duct air is the principal source of room infection, where direct upper and lower air irradiation may be impracticable as in low ceilinged houses and railway cars, or where it may be desirable to disinfect recirculated air for the purpose of obtaining increased sanitary ventilation, or to justifying decreased make-up air. Since the recirculated air is usually four or five times the volume of the make-up air, disinfection of the former will increase four or five fold any disinfecting value which may have been credited to the latter, or disinfection of recirculated air may leave little need for make-up air except for odor and carbon dioxide control. In hospitals duct air disinfection may make air conditioning and heating by recirculation practicable to an extent not now thought safe or permissible.

There are many places where it is desirable to make the air carried by a duct equivalent to outdoor air in freedom from live bacteria. This can be easily done with General Electric germicidal lamps but the number required is not so simply determined as for the upper air of rooms because of the high and variable air speeds and the great variations in duct shapes.

Duct air at speeds up to 1000 fm may be disinfected a theoretical 99% by installing germicidal tubes directly in the ducts. The total ultraviolet watts (uvw) required in non-reflective ducts may be calculated from the formula

$$(5)\quad \text{uvw} = \frac{\text{cfm}}{3 \times d}$$

where d = minor or lesser duct dimension in inches and is not exceeded more than 50% by the major dimension.

This equation was used to prepare Appendix Fig. A23.

Table VIII samples the use of Formula 5 and Appendix Fig. A23.

Table VIII

Theoretical 99% Disinfection of Air at 80°F. in Non-reflective Ducts. — C. F. M.

No. of 8-watt G.T.		2	4	8	16					
No. of 15-watt G.T.		1	2	4	8	12	16			
G36T6 at 420 ma.				1	2	3	4	5	7	10
Lesser Dimension of Ducts Inches	5	40	80	160	320					
	6	48	96	182	384	576				
	7	56	112	224	448	672	896			
	8	64	128	256	512	768	1024	1280		
	9	72	144	288	576	864	1152	1440		
	10	80	160	320	640	960	1280	1600	2240	
	15	120	240	480	960	1440	1920	2400	3360	4800
	20	160	320	640	1280	1920	2560	3200	4480	6400
	25	200	400	800	1600	2400	3200	4000	5600	8000
	30		480	960	1920	2880	3840	4800	6720	9600
	50			1600	3200	4800	64000	8000	11200	16000
	100				6400	9600	12800	16000	22400	32000
	200					19200	25600	32000	44800	64000

The above table is for ducts with non-reflective walls and an air temperature of about 80°F. The number of tubes required should be increased 10% for temperatures of either 50° or 100°F. by 20% for 40° or 110°F. and by 30% for 35°F. when 15- or 30-watt tubes are used. This is the effect of cooling or heating the tubes. The above table is for a relative humidity of 60% and the number of tubes should be increased by 50% for 70% rh., by 65% for 80% rh., and by 75% for 90% rh. A theoretical 99% disinfection of air can also be obtained with one-half the above number of tubes with duct walls of a 75% reflectance. A theoretical 90% disinfection is obtained with one-half the above number of tubes and non-reflective duct walls.

Slimline G36T6

The G36T6 tube was developed especially for use in air ducts where the cooling effect of moving air may adversely affect the life and output maintenance of other tubes. It is made of a glass similar to fused-quartz which reduces the early life depreciation characteristic of other glasses. The tube needs no high voltage starting devices and so may be installed in ducts and rooms containing explosive atmospheres. It may be operated at tube currents of 120, 200, 300 and 420 milliamperes. The 300 and 420 milliampere operation is only for use in cold air ducts to maintain ultraviolet output. See footnote of Table VIII.

Duct Example

A 20″ x 30″ duct carrying 3000 cfm would call for $\text{uvw} = \frac{3000}{3 \times 20} = 50$ ultraviolet watts. This could be supplied by four G36T6 germicidal tubes operated at 420 milliamperes for a total initial output of 58 ultraviolet watts, or an average through life of 48 watts.

In the frequent case of flat ducts having one dimension two or more times as great as the other there should be reference to more detailed methods of calculation available elsewhere, but the maximum tube requirements may still be determined from For-

Fig. 15. Typical plenum chamber installation of germicidal tubes.

In large ducts and plenum chambers germicidal tubes may be assembled like the rungs of a ladder in vertical frames supported out in the center of the chamber in whatever series or multiple arrangement best fits the local conditions and provides access for cleaning and replacement, Fig. 16 (D). In very large ducts, where the air speeds are relatively low, the tubes should be so placed, when possible, as to provide a maximum average distance from the tubes to the duct walls in directions perpendicular to the tubes, and regardless of the direction of air movement.

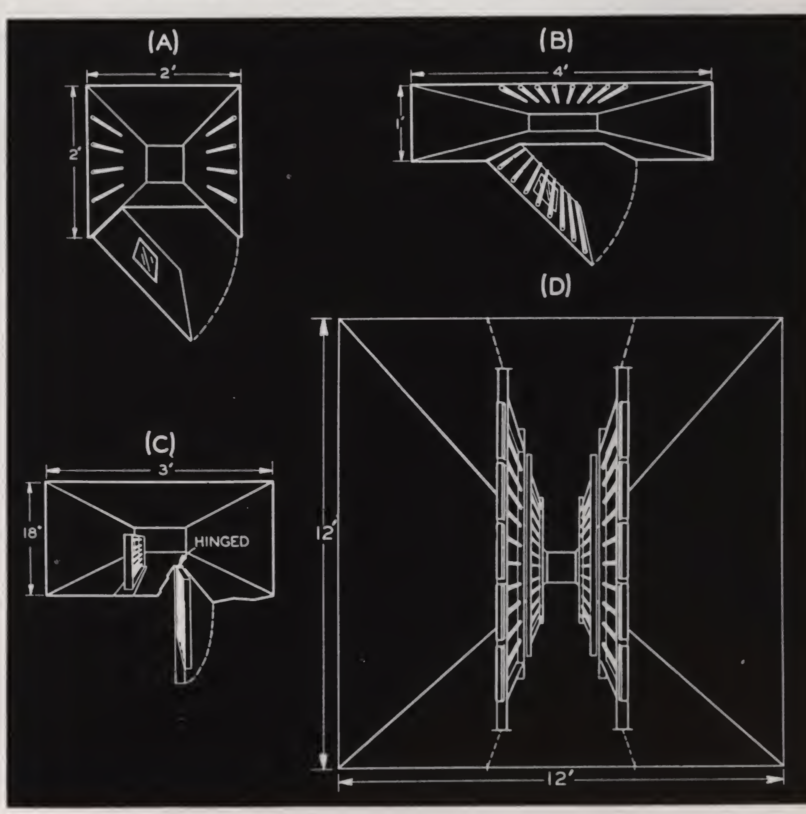
There is a special installation problem in case of flat ducts which may have one dimension four to six times the other. Such a duct cross-section limits the effectiveness of the tubes not only in proportion to the lesser dimension, but also because little of the duct volume beyond the actual location of the tubes is useful for air irradiation. In such cases the tubes should be distributed only over the longer duct wall shown in Fig. 16 (B).

Fig. 15 shows a typical large duct installation providing a total of 120 ultraviolet watts, average through tube life, from germicidal tubes placed adjacent to the dust filters.

mula (5) or Appendix Fig. A23 by subdividing the duct and the air capacity so that the dimensions of the subdivisions fall within the range of the tables.

The mechanical details of a germicidal tube installation follow closely those of the dust-filter installation and it is anticipated that manufacturers will provide similar standard-unit assemblies. Although there are many ways of installing germicidal tubes in air ducts, the best compromise in small ducts is by placing them lengthwise on the duct wall, on 4- to 5-inch centers grouped in the center half of the duct walls and out of the corners of rectangular ducts. The duct walls near the tubes and the duct in both directions from them should be of polished chromium plate or aluminum if the conditions are such that the reflective duct walls can be easily cleaned whenever the lamps are cleaned. Since the germicidal tubes must be kept reasonably free of dust, there must be convenient access for cleaning. This usually can be arranged by hinged panels on the sides or the bottom of the duct, and, if necessary, the tubes may also be mounted on these panels as well as on the stationary duct walls, Figs. 16 (A) and (C).

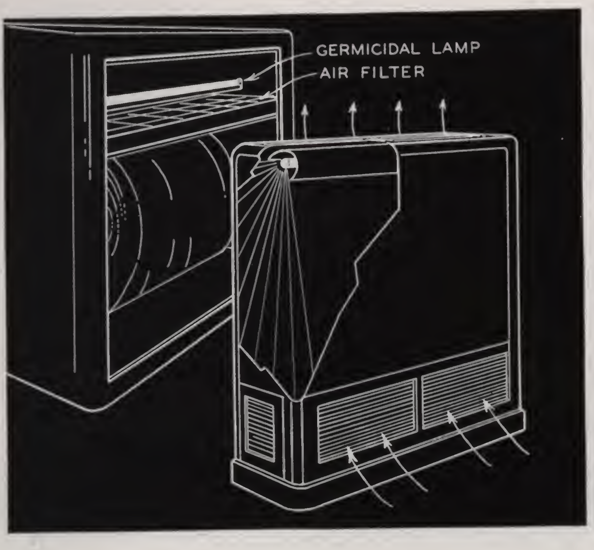
Fig. 16. Schematic sketches of typical duct installations.



Short Run Ducts

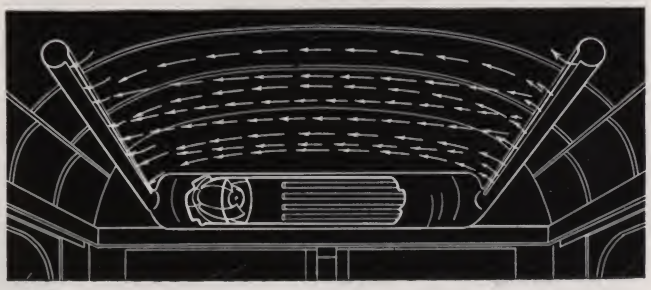
It is sometimes necessary to place lamps in short run ducts, between dust filters and heating or cooling coils, for example, where the effective length of the irradiated space is less than the minor dimension of the duct. In such cases this effective length of the duct should be used instead of the minor dimension of the duct in applying Formula 5 or Table VIII, or Appendix Fig. A23.

In such a room air conditioner as here sketched there might be available an irradiation chamber with dimensions 24″ x 36″ x 9″ rated at 600 cfm. Regardless of the direction of the air flow, it should be treated as a 9″ x 36″ duct calling for 20 uv-watts. This ultraviolet could be supplied by two G36T6 slimline tubes for a theoretical 99% disinfection. One half as much ultraviolet or one G36T6 tube would provide a theoretical 90% disinfection. In this case the dimensions of the chamber leave no choice of tube position. They should be centered in a plane halfway between the 24″ x 36″ sides of the chamber or on one of the sides. Two lamps should be spaced 10—12″ apart.



Air Circulators

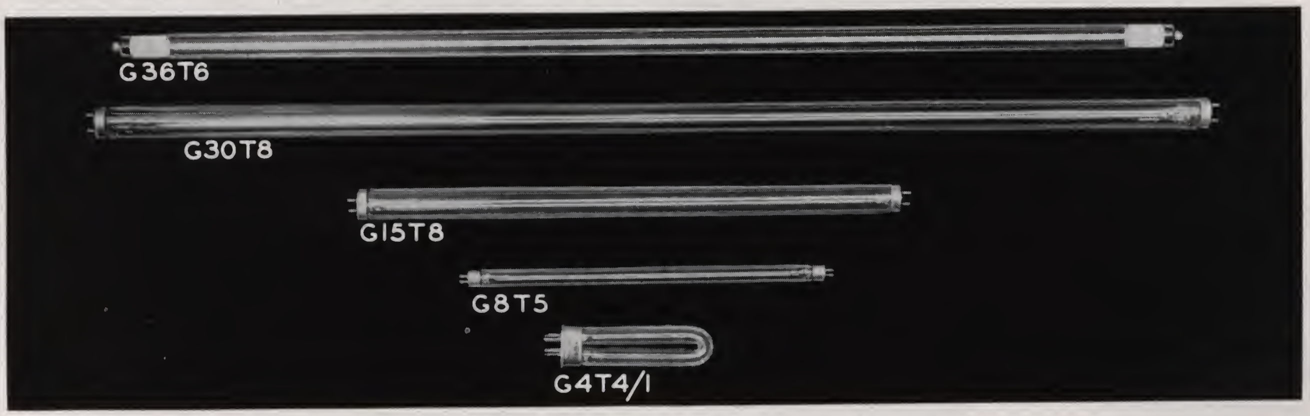
There are many places where air disinfection is desirable but not practical, by the upper air method because of a low ceiling, or by the usual duct method because of an inadequate duct service or none at all. In such cases the equivalent of a local air recirculator may be provided as has already been suggested for elevator cabs. Such a recirculating air disinfector for use in buses may take the form of a coaxial fan in a 6—7-foot length of circular duct containing several germicidal lamps and connected directly to air supply and return ducts lengthwise of each side ceiling. A 500 cfm fan in a 12-inch duct containing two 30-watt lamps would provide air disinfection in a 30-passenger bus equivalent to an air change every two minutes or 30 per hour.



GERMICIDAL TUBE DATA

	G-30 T-8	G-15 T-8	G-8 T-5	G-4 T-4	G-36 T-6
Rated Watts	30	15	8	4	16 to 36
Over-all length ①	36″	18″	12⅛″	5¾″	36″
Diameter	1″	1″	⅝″	½″ ⑨	¾″
Circuit Voltage	See Auxiliary	See Auxiliary	See Auxiliary	110–125	See Auxiliary
Approximate amperes	.355	.31	.16	.08	.12 to .42
Life (hrs.) rated (3 hr. operating periods) ②	2500 ③	2500 ③	2500	2500	2500 ④
Bulb designation	T-8	T-8	T-5	T-4	T-6
Ultraviolet output watts (2537A) ⑦	7.0	2.9	1.5	.5	6.3 to 11.6 ⑩
Maximum intensity perpendicular to tube ⑦ ⑧ milliwatts per sq. ft. at 10 ft.	7.2	3.2	1.7	0.65	6.5 to 12
Base	Medium Bipin	Medium Bipin	Miniature Bipin	Radio 4-Contact	Single Pin same as Slimline
Auxiliary	⑤Same as for 30-w Fluorescent lamp	⑥Same as for 15-w Fluorescent lamp	⑥Same as for 8-w Fluorescent lamp	58G827—60 cy. 58G828—50 cy.	⑤Same as 42T6 Slimline
Starter	FS-4	FS-2	FS-5	FS-5	None

① Including standard lampholders. ② Under specified test conditions.
③ Where tubes are operated continuously (essentially without current interruption), the rated life is 4000 total burning hours.
④ Where tubes are operated 12 hours or more per start, the rated life is 6000 total burning hours.
⑤ For circuit voltages 110–125 (50 or 60 cycles), and 220–250 (50 or 60 cycles).
⑥ For circuit voltage 110–125 (50 or 60 cycles).
⑦ Average at 100 hours life, initial rating 25% higher, average through life 85%.
⑧ Multiply by 10 for microwatts per cm² at one meter.
⑨ Bent tube construction makes lamp approximately one inch in width.
⑩ 6.3 at .12 amp., 8.7 at .20 amp., 10.6 at .30 amp., and 11.6 at .42 amp.



BASIC GERMICIDAL TECHNICAL DATA

Exposures (intensity x time) for 99% kill.

Typical bacteria, 25 ultraviolet milliwatt-minutes per cu. ft.

Typical molds, 250 to 2000 ultraviolet milliwatt-minutes per cu. ft.

Desirable intensities for air disinfection of typical bacteria.

Upper air, 25 to 5 ultraviolet-milliwatts per sq. or cu. ft.
99% kill in 1 to 5 minutes.

Duct air, 10,000 to 2500 ultraviolet-milliwatts per sq. or cu. ft.
99% kill in 0.0025 to 0.01 minutes or ⅛ to ½ second.

Reflection factors for 2537A—per cent.

Aluminum-treated 70—85, Alzak 65—75, mill 40—60, paint 40—75.
Chromium plate 45—55 Stainless steel 20—30
Vitreous enamel 5—10 Average oil paints 5—10
Acoustic plaster and wallboard 10—20
"White-coat" plaster 40—60

Permissible intensities on faces.

American Medical Association, Council on Physical Medicine.

Constant exposure of infants' faces,
0.1 microwatts per sq. cm. or 0.0001 watt per sq. ft. at the face.

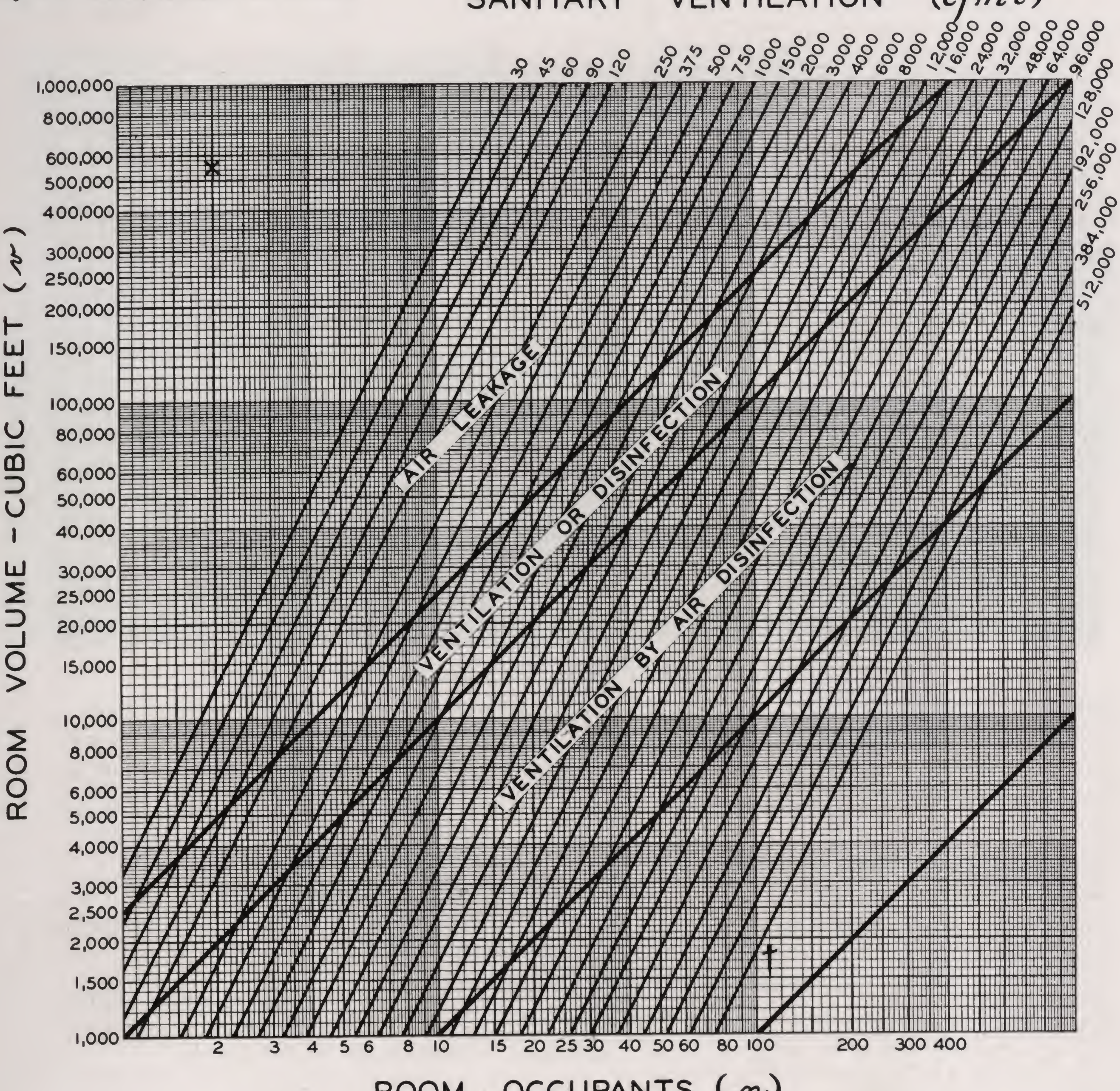
Seven hours, or less, per day,
0.5 microwatts per sq. cm. or 0.0005 watts per sq. ft. at the face.

Sanitary Ventilation — Calculation of Need

Until there has been some official specification of the amount of ventilation needed to reduce the spread of respiratory diseases Formula (2) of this bulletin will be used. It was used to prepare Fig. A17 of this Appendix. Over the area to the upper left normal air leakage and large room volume per person provides adequate air sanitation. The extreme upper left represents outdoor conditions. Two people, far apart, in a theatre large enough to seat 2000 are represented by the *. Through the narrow area diagonally up across the chart enough sanitary ventilation can be supplied by adding ventilation or air disinfection to the normal air leakage. This may be by outdoor air or disinfected air through ducts or by disinfected air from the upper part of the room.

Over the next area to the lower right one must add much, five fold, to the air leakage and the maximum practical to filter, heat, circulate and recirculate with disinfection. The next area represents impractical human crowding. The condition in a certain infamous concentration camp where all were dead or unconscious after 14 hours without ventilation is represented by the †. The sanitary ventilation suggested by Fig. A17 of 600,000 cfm would have required a 35-mile per hour wind through the prison room. It would doubtless have also prevented droplet infec-

Fig. A17. Sanitary ventilation and crowding.



tion. Assuming a headlevel or germicidal fixture-to-ceiling distance of two feet the ultraviolet intensity from Fig. A18, to provide an equivalent sanitary ventilation by irradiation would have been 5000 milliwatts, or five ultraviolet watts, per sq. ft. Such intensities are impractical outside of an air duct. The reflected ultraviolet, would, theoretically, have burned the faces of the prisoners within a minute.

The extreme lower right represents impossible human crowding.

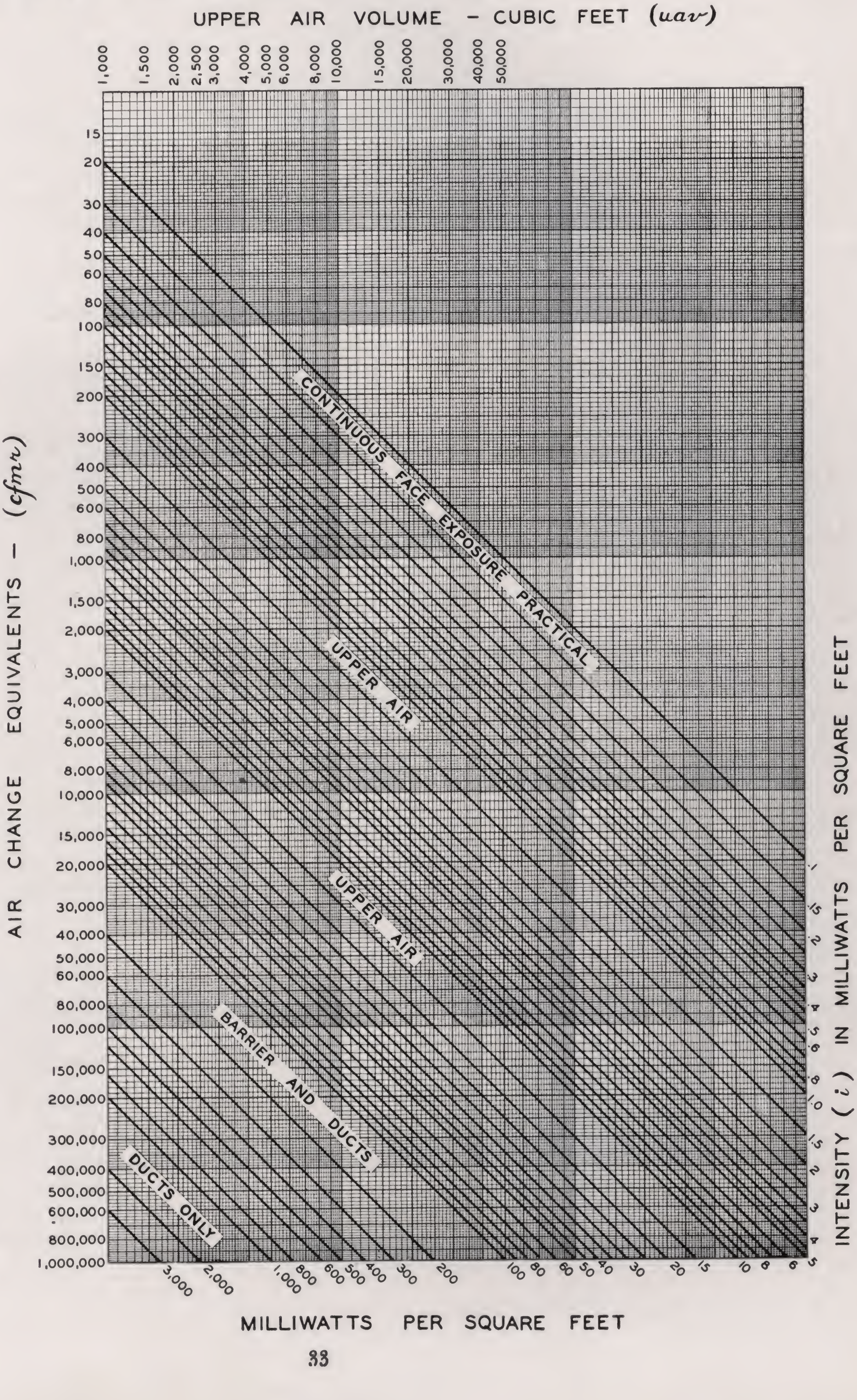


Fig. A18. Air change equivalents of ultraviolet air disinfection.

GENERAL SPECIFICATIONS OF FIXTURES

Louvered fixtures should meet the following specifications:

(a) The intensity of ultraviolet energy in the horizontal plane of the tube, and in the direction of a plane 30° above the horizontal, should be less than twice the intensity of the tube lamp, and there should be no direct radiation from the fixture in the directions (10° below the horizontal plane or 40° above it).

(b) The direction of maximum intensity should be 12° ± 3° above the horizontal plane of the tube, and this maximum intensity should be at least four times that of the bare tube.

The above specifications and tolerances are illustrated by spatial distribution curves below.

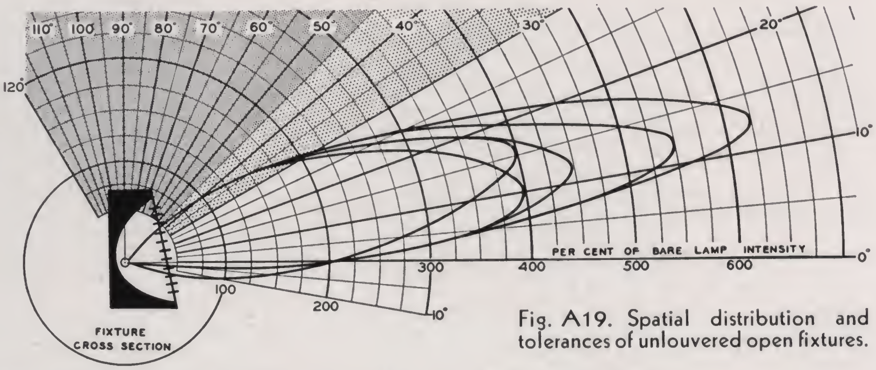


Fig. A19. Spatial distribution and tolerances of unlouvered open fixtures.

Open or unlouvered fixtures should meet the following specifications:

(a) The intensity of the ultraviolet energy in the horizontal plane of the tube, and in the direction of a plane 50° above the horizontal should be less than twice the intensity of the bare tube, and there should be no direct radiation from the fixture in directions 10° outside this zone (10° below the horizontal plane or 60° above it).

(b) The direction of maximum intensity should be 16° ± 7° above the horizontal plane of the tube, and this maximum intensity should be at least four times that of the bare tube.

The above specifications and tolerances are illustrated by typical spatial-distribution curves.

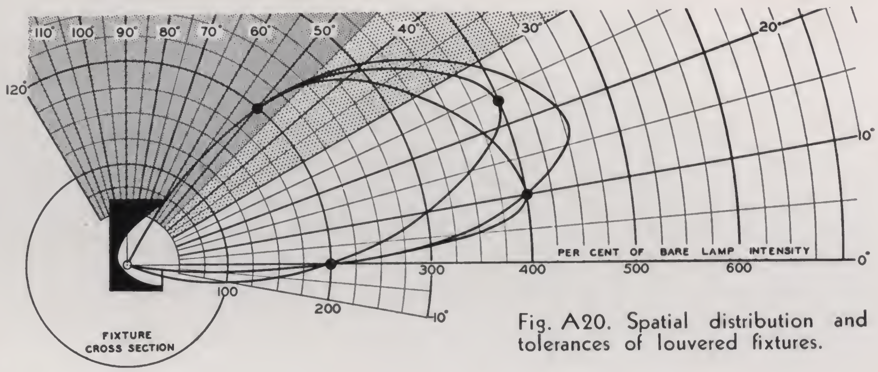


Fig. A20. Spatial distribution and tolerances of louvered fixtures.

Small Open Fixtures

A comparison of Figs. A19 and A20 shows the limitations of some small open fixtures. They are high in intensity toward a nearby ceiling and low in intensity in effective directions below the ceiling.

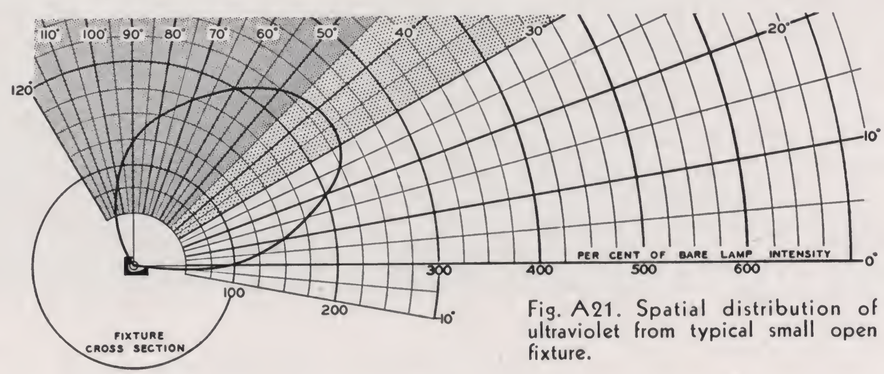


Fig. A21. Spatial distribution of ultraviolet from typical small open fixture.

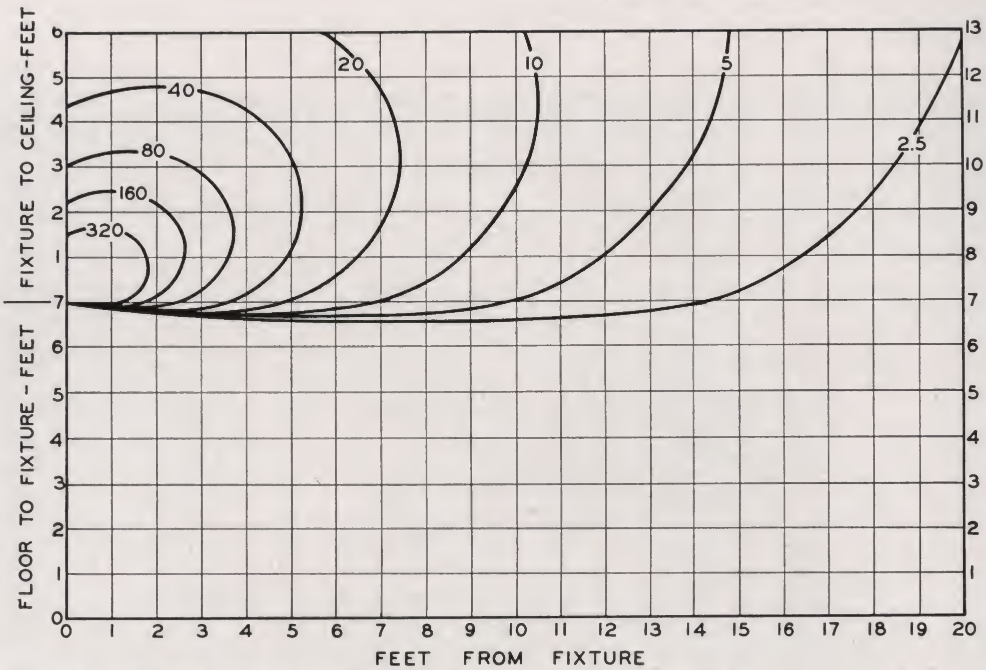


Fig A22. Isotensity lines of typical small open fixture — milliwatts per sq. ft.

Table A-IX

Average Ultraviolet Intensity Factors for Typical Small Open Fixture of Figure A21.

Distance — ft. / Areas — sq. ft.		10 / 100	12 / 150	14 / 200	16 / 250	18 / 325	20 / 400	22 / 500	24 / 600
Fixture to Ceiling Feet	5	3.74	2.88	2.27	1.82	1.52	1.27	1.07	.90
	4	4.65	3.43	2.65	2.07	1.68	1.40	1.16	.98
	3	5.96	4.20	3.13	2.44	1.93	1.58	1.32	1.12
	2	7.90	5.28	3.82	2.90	2.27	1.83	1.53	1.28
	1	4.50	2.95	2.10	1.58	1.23	1.00	.84	.68

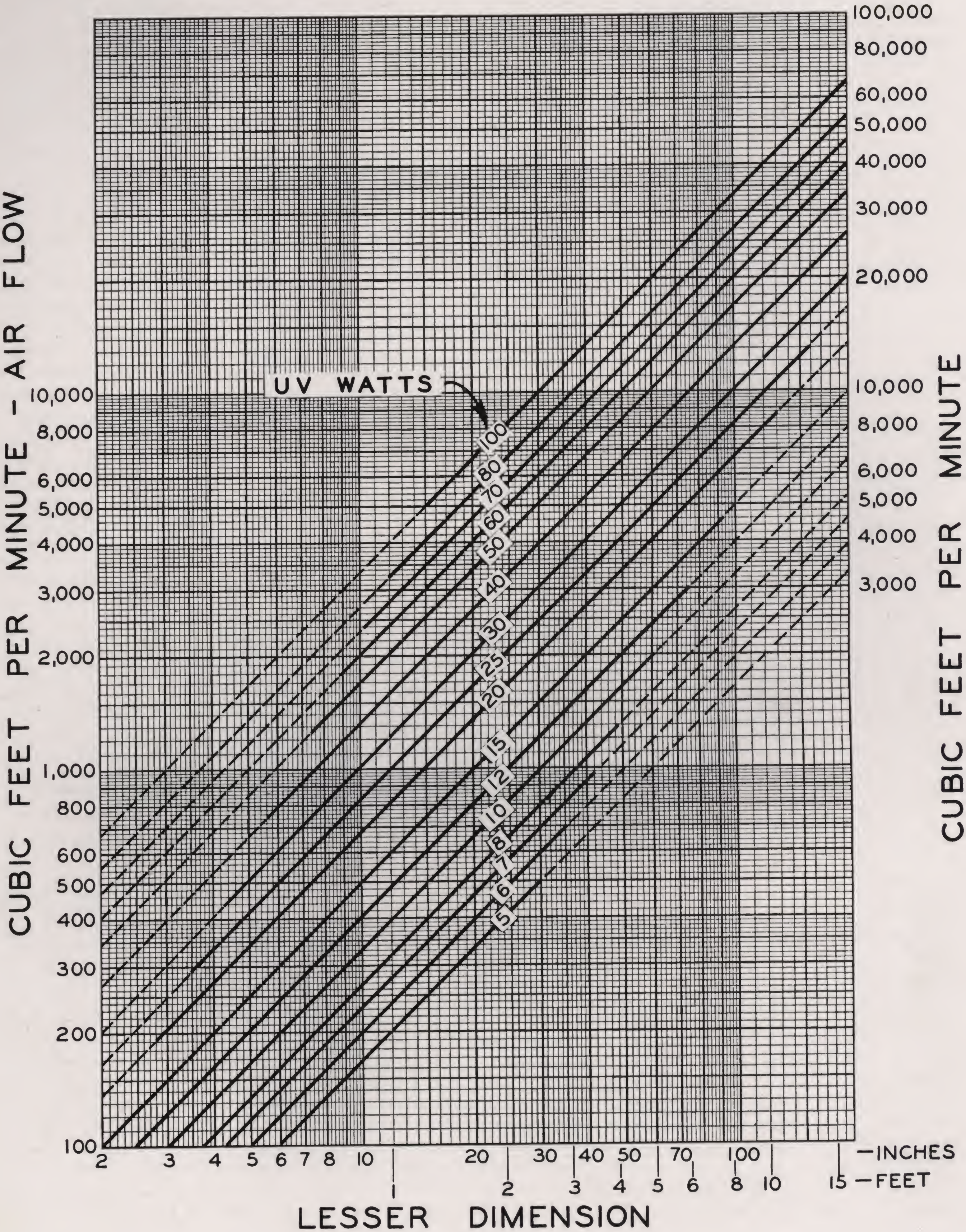
Multiply above factors by ultraviolet watts output rating of tube to determine average intensity in various upper air volumes.

Table A-X

Average Ultraviolet Intensities in Milliwatts per sq. ft. Produced by 30-watt Germicidal Tube (6 Ultraviolet Watts) in Typical Small Open Fixture of Figure A21.

Distance — ft. / Areas — sq. ft.		10 / 100	12 / 150	14 / 200	16 / 250	18 / 325	20 / 400	22 / 500	24 / 600
Fixture to Ceiling Feet	5	22.4	17.3	13.6	10.9	9.1	7.6	6.4	5.4
	4	27.9	20.6	15.8	12.4	10.1	8.4	6.9	5.9
	3	35.8	25.2	18.8	14.6	11.6	9.5	7.9	6.7
	2	47.3	31.7	22.9	17.4	13.6	11.0	9.2	7.7
	1	27.0	17.7	12.6	9.5	7.4	6.0	5.0	4.1

Fig. A23. Theoretical 99% disinfection of air at 80°F. in non-reflective ducts. See Table VIII for note on effect of temperature and humidity.



Air Disinfection in Ducts

For ducts whose greater dimension does not exceed the lesser by more than 50%, and with non-reflecting walls, the ultraviolet watts for a theoretical 99% disinfection of respiratory disease germs and viruses is shown on the Haynes' chart, Fig. A23. Relative humidities in excess of 65% and extremes of air temperature increase the ultraviolet requirements.

The number of germicidal tubes required may be determined by dividing the total watts by the average-through-life rating in ultraviolet watts of any commercially available germicidal tube. The chart may be interpolated and extrapolated by noting that the ultraviolet watts required are directly proportional to the cubic feet per minute and inversely proportional to the lesser dimension of the duct.

The Haynes chart, Fig. A23, is for ducts with non-reflective walls and an air temperature of about 80° F. The ultraviolet watts required should be increased 10% for temperatures of either 50° or 100° F by 20% for 40° or 110° F and by 30% for 35° F when 15- or 30-watt tubes are used. This is the effect of cooling or heating the tubes. The chart is for a relative humidity of 60% and the ultraviolet watts should be increased by 50% for 70% rh., by 65% for 80% rh., and by 75% for 90% rh. A theoretical 99% disinfection of air can also be obtained with one-half the above ultraviolet watts with duct walls of a 75% reflectance. A theoretical 90% disinfection is obtained with one-half the above ultraviolet watts and non-reflective duct walls.

Cubic-foot-lethe-disinfection

This is a proposed unit of air disinfection. It is the disinfection of a cubic foot of air produced by one air change—dilution with continuous mixing—theoretical removal of 63.2%. It is also the disinfection of a cubic foot of air produced by one equivalent air change—exposure for one minute to an ultraviolet irradiation of five milliwatt-ft. per cu. ft.—theoretical killing of 63.2%.

Ultraviolet Intensity for Upper-Air Disinfection

Assuming irradiation with an ultraviolet intensity of five milliwatt-ft. per cu. ft. to kill bacteria at the same rate as they could be washed out of the same place by dilution with fresh air at a rate of one cubic foot of diluent per minute per cubic foot of contaminated air, Formula (3) of this bulletin follows directly. It was used to prepare Fig. A18. It is useful to note that the theoretical disinfection of 63.2% per minute provided by an average intensity of five milliwatts per square foot makes 63.2% of the irradiated air equivalent to outdoor air for sanitary ventilation. Or for example, a 90% disinfection of a circulating upper air volume of 3300 cubic feet provides 2970 cubic feet of air for sanitary ventilation.

Foot-watt of Irradiation

This is a proposed unit of ultraviolet irradiation. It is one ultraviolet watt, or 1000 ultraviolet milliwatts, effective on one square foot of surface or through one cubic foot of space. The total irradiation in a room is calculated in this unit by multiplying the volume of the irradiated space by the average ultraviolet intensity throughout that space. One foot-watt of irradiation provides 200 cubic-foot-lethes of disinfection or 200 air change equivalents of ventilation.

Watts Output and Intensity

When germicidal lamps are used to irradiate surrounding surfaces the average intensity on those surfaces times their total area equals the ultraviolet output of the tube. Not so when air is irradiated because it has almost no absorption. The total output of the germicidal tube is effective in and through successive surrounding layers of air out to the enclosing walls. So the total calculated foot-watts of irradiation is not simply related to the tube output. It is the integrated product of the output in various directions by the corresponding distances to enclosing walls. It is also the product of the volume of the irradiated space by the average ultraviolet intensity throughout the space. The latter is the method used in this bulletin.

The ultraviolet watts referred to in this bulletin are always the actual output into space, from the bare tubes when in air ducts, or from enclosing fixtures for upper air use (25—50% of tube). Early publications on the theory of upper air disinfection treated the total bare tube output as if effective in producing irradiation with results difficult to compare with those in this bulletin.

Air Sampling—Methods and Interpretation

All bacteriologic air samplers are basically dust-collecting devices modified or used in such a manner as to permit a count only of the colonies resulting from culturing "living dust" in the form of bacteria, yeast, and mold spores. None of these devices detect virus organisms. The devices in recent use may be described as Petri dishes and the "Aeroscope," slit and sieve impinging devices, the air centrifuge, and, very recently, the Luckiesh-Taylor electrostatic and rotating slit devices. Some progress is being made in determining conversion factors relating these devices or methods, but especially in practical field work, each method has characteristics adapting it to certain special conditions and these very characteristics make intercomparison of measurements difficult. The following carefully prepared paragraphs should be kept in mind in reading any and all reports of bacterial air sampling for the appraisal of researches and practical results in air disinfection.

Harmless Bacteria Dominate Air Contamination

The fundamental difficulty in the bacteriologic examination of air, as well as water and milk, is that it always contains a very large number of living, usually saprophytic, organisms capable of developing colonies, but which are harmless and mostly not even of human origin. Even under conditions of extreme contamination by respiratory disease germs, the relative number of such disease germs per cubic foot is so very small as to make the number that it is possible to capture out of 5 to 10 cubic feet of air of limited statistical significance. It is for this reason that in the routine examination of milk and water no attempt is made to look for disease producing organisms. Instead, the test is for E-coli, considered to be an indication of contamination by sewage, known to be, in turn, a possible source of contamination by such water-borne diseases as typhoid fever.

There are organisms universally characteristic of the human nose and throat which can be used as indices of the amount, rather than the kind, of air contamination by people. As with E-coli in water, they are presumptive evidence of the presence of respiratory disease germs and of respiratory disease viruses impossible of direct detection by the sampling devices. But there has not yet been established any direct bacteriological index of air contamination by pathogenic organisms. Neither are there sufficiently sensitive techniques for directly identifying streptococcic and staphylococcic organisms, regardless of whether or not they are disease-producing types, to permit their use as indices of pathogenic contamination except under most unusual conditions of exceptionally high contamination such as can occur in hospital wards devoted solely to the care of streptococcic infections.

Dust–Contaminated

Superposed on this basic difficulty is the well-known fact that relatively heavy dust particles, disturbed from the side walls and floor of a room by any activity in it, are highly contaminated with living organisms very similar in nature and relative numbers to those contaminating the air itself.

There is, moreover, no reason to believe that the ratio of pathogenic to harmless organisms free floating in the air is the same as the ratio of pathogenic to harmless organisms attached to dust particles. It is this fact which introduces the greatest uncertainty in the results secured by the various air sampling devices which differ greatly in their selectivity between contaminated dust and truly air-borne organisms not attached to dust particles. At the one extreme lies the Petri dishes which sample by sedimentation from the air relatively nothing but contaminated dust particles even after hours of exposure. The other air sampling devices do better only to the extent that they add to the contaminated dust a more or less effective but never complete sampling of unattached free floating organisms.

Another complication is that the nonpathogenic organisms are, in general, considerably more resistant to ultraviolet killing than are streptococcic, staphylococcic and other respiratory disease organisms of human origin. Also, both pathogenic and nonpathogenic organisms attached to dust particles are afforded a protection by the relatively large dust particles. This protection varies over a considerable range depending upon whether the irradiation of the air containing the organisms is entirely in one direction or, in effect, by crossfire from opposite directions. This protective variation may theoretically be as great as 1 to 2 or 3, depending upon the kind of dust particles and the distribution of ultraviolet energy.

Air Sampling Always Partial

The final effect of all these variables is that, regardless of the device used, the air sampling is partial and dominated both before and after ultraviolet air disinfection by the highly-resistant nonpathogenic organisms and dust protected organisms. There is no sampling of virus organisms in any case. It is for these reasons that in air disinfection studies under practical conditions where both the contamination and the sampling is entirely dominated by dust protected and by nonpathogenic organisms of other than human origin, the results can be entirely different from those obtained when the air has been artificially contaminated by organisms, either E-coli or from human saliva, so that the total contamination is dominated by truly air-borne organisms. There is accumulating evidence that when conventional air sampling methods indicate a total over-all reduction by ultraviolet disinfection of 25% to 50% in the dust carried and resistant nonpathogenic contamination of the air in typical occupied rooms there has been about double that reduction in the contamination by truly air-borne organisms of human origin.

Electrostatic Bacterial Air-Sampler

Electrostatic Bacterial Air-Sampler—Fig. A20.
(Luckiesh-Holladay-Taylor)

G-E specialists in bacteriology have devised this extraordinary instrument of high efficiency and convenience in collecting air-borne micro-organisms. This device greatly improves on former methods of air sampling by collecting on the culture medium for tabulation, the concentration of all micro-organisms, regardless of origin, in a given volume of air.

Operating at 110-120 volts a-c, the air-sampler employs a high voltage electrostatic field (approximately 7000 volts) to precipitate organisms into two specially prepared Petri dishes.

Useful in countless ways in germicidal researches, the air-sampler will also prove indispensible in field investigations. It will reveal both the need for, and the result of, germicidal installations. Its simple, quiet operation permits its use in an occupied room without distracting the occupants.

Fig. A24. Electrostatic Bacterial Air Sampler.

This unit is designed distinctly for highly scientific work in the field of bacteriology and is intended for the use of skilled laboratory technicians.

Permissible Exposure on Faces

American Medical Association, Council on Physical Medicine.

Constant exposure of infants' faces,
0.1 microwatts per sq. cm. or 0.0001 watt per sq. ft. at the face.

Seven hours, or less, per day,
0.5 microwatts per sq. cm. or 0.0005 watts per sq. ft. at the face.

Maximum Daily Exposures

Exposure Time per 24 hours	Intensity on Faces milliwatts/ft.	Exposure Time per 24 hours	Intensity on Faces milliwatts/ft.
24 hr.	0.1③	2 hr.	1.8
18 hr.	0.2③	1 hr.①	3.6
12 hr.	0.3	30 min.	7.2④
9 hr.	0.4	10 min.	21.6④
6 hr.	0.6	1 min.②	216.0
4 hr.	0.9	30 sec.	432.0
3 hr.	1.2	5 sec.	2.6 watts/ft.^{2}

① Exposures (time x intensity) 3.6 milliwatt hrs./ft.^{2}

② Exposures (time x intensity) 216 milliwatt min./ft.^{2}

③ Permissible intensity in hospital infant wards — one-fiftieth or one-hundredth that recommended for hospital air disinfection.

④ Intensity recommended for hospital upper air disinfection — tolerated only 10 — 30 minutes if on faces of personnel.

Eyes — Protection and Treatment

Experience indicates it to be inevitable that experimenters with germicidal energy learn respect for it only by painful experience, which usually takes the form of a reddening of the face and a smarting sensation in the eyes appearing two or three hours after exposure and varying in intensity with the length of exposure. While this effect is often called an erythema, it is much more superficial in nature than that produced by ultraviolet energy of a longer wavelength, the penetration of the skin being so slight, for example, that it is difficult to produce the blistering easily resulting from long exposure to ultraviolet in the suntan range. The skin irritation disappears in a day or two leaving little pigmentation.

It has been found that the discomfort from ultraviolet irritated eyes may be strikingly relieved by exposing the surface of the eyeball for 15 to 20 minutes to as high an intensity of heat as can be comfortably borne from any available heat lamp or from an ordinary incandescent lamp held close to the eye. In extreme cases a doctor should, of course, be consulted but when this is impractical, the usual first-aid treatment is to drop sweet oil into the eyes and to apply ice packs. In any case the irritation produced by germicidal tubes disappears within a day or two and much more quickly than a corresponding degree of irritation produced by the longer wave ultraviolet. There is apparently no permanent injury, and no such hypersensitivity to sunlight as sometimes results from eye burns produced by high intensity quartz mercury arcs, by carbon arcs and by welding arcs.

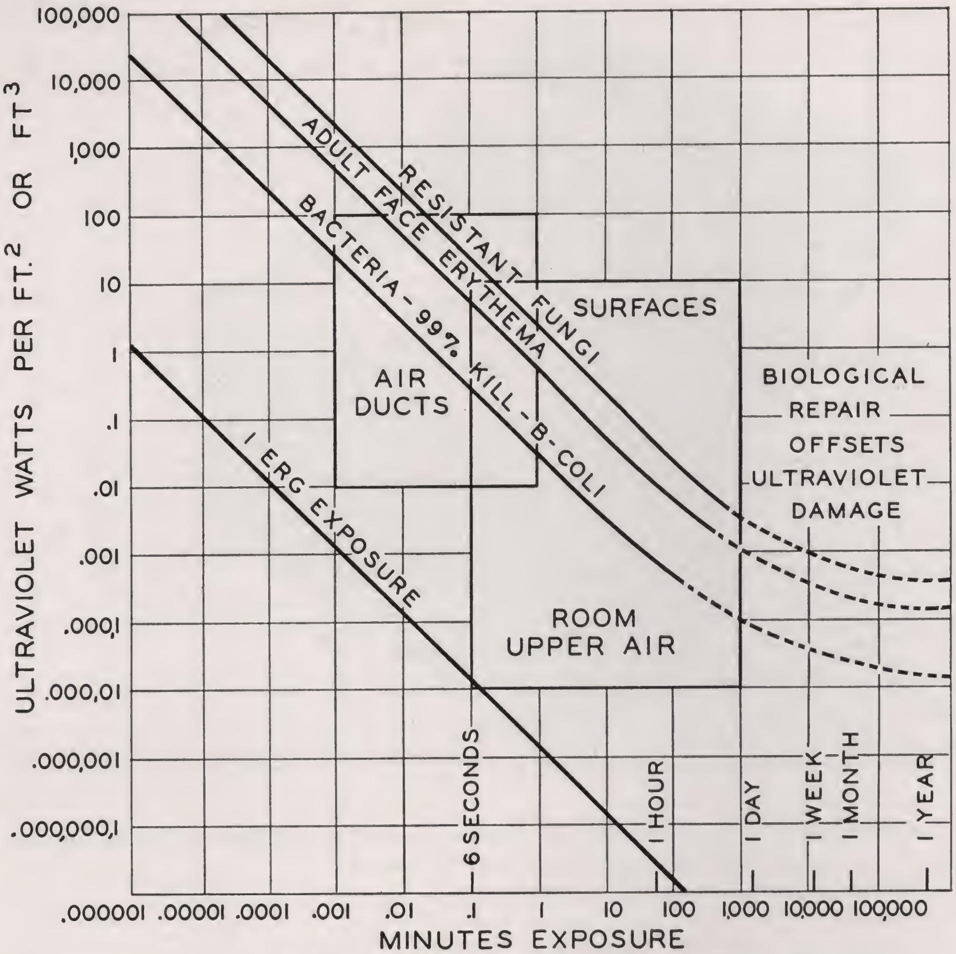


Fig. A25. Time and intensity for various exposures.

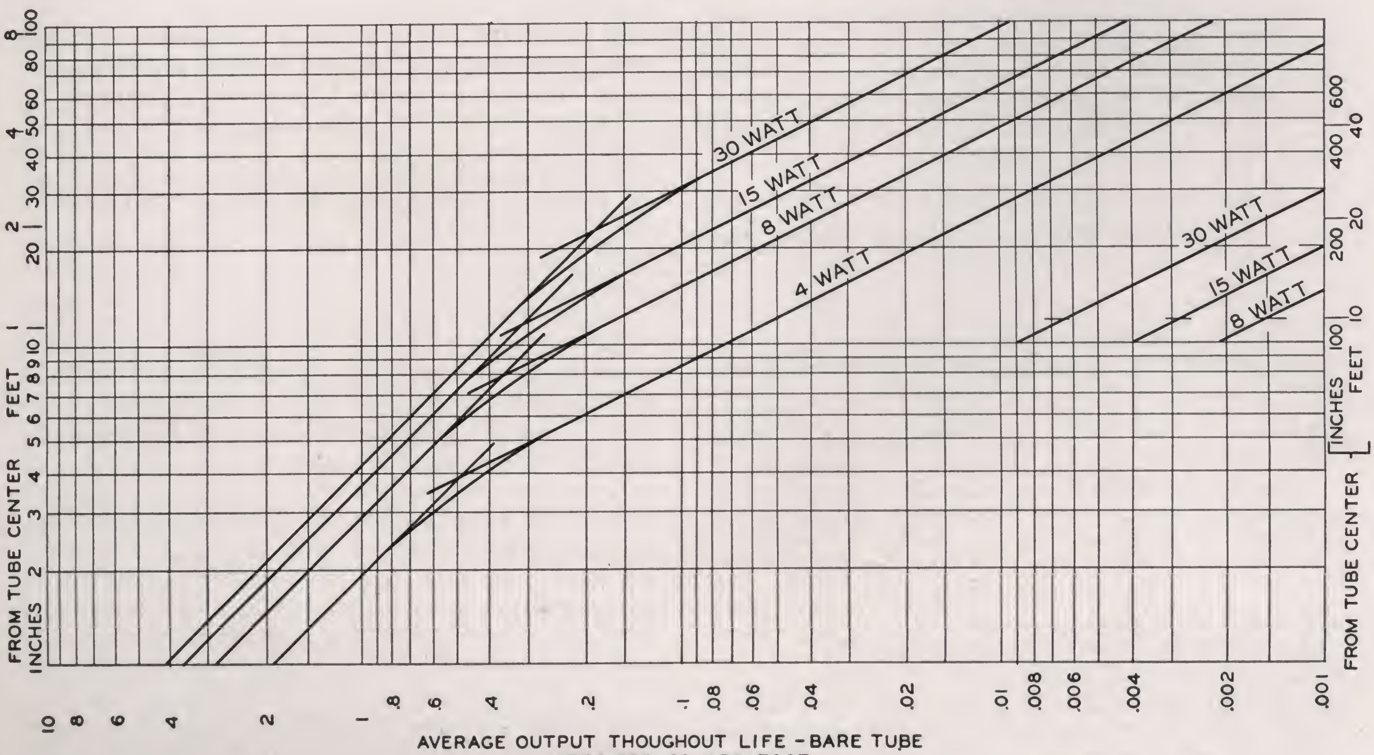


Fig. A26. Variation of ultraviolet intensity with distance from bare germicidal tubes.

GLOSSARY

Glossary of Terms Associated with Air Sanitation

AIR SANITATION—Bacterial reduction by ventilation or disinfection. See SANITARY VENTILATION.

AIR-SAMPLING—Bacterial air sampling is the determination of the concentration of bacteria, mold spores or yeast cells in air, per cu. ft., or on surfaces, per sq. ft. Viruses cannot be easily sampled.

AIR-BORNE—Suspended in air for minutes and hours. Characteristic of finest dust, bacteria and mold spores and in contrast with larger dust particles which settle out of air in seconds.

ANGSTROM UNIT—Å—A physical unit of length equal to 1/100,000,000 of a centimeter or .003937 millionths of an inch. Used in expressing the wavelength of radiant energy.

10A = 1 millimicron — mu
10,000A = 1 micron — u
10,000,000A = 1 millimeter
100,000,000A = 1 centimeter

BACTERIA-BACTERIUM sing.—A group of single celled living organisms, microscopic in size, belonging to the plant kingdom. Some live best on dead organic material, others find conditions favorable to their growth in living animals. These latter include the disease-producing or pathogenic organisms.

BARRIER-ULTRAVIOLET — Ultraviolet, usually from a louvered type of fixture and usually in a vertical direction, of an intensity which will kill ordinary bacteria during a single passage through. Ultraviolet barriers are usually placed in door openings, across corridors or across the front of infant cubicles.

CEILING REFLECTANCE—The extent to which ceiling surfaces reflect germicidal ultraviolet—5—10% for oil paint—30—50% for gypsum products (white-coat-plaster Keene's cement, plaster of Paris).

CIRCULATION-AIR—The movement of air through an enclosed space.

CROSS INFECTION—The transmission of a disease from one person to another, especially in enclosed spaces.

DIE-AWAY—DECAY—The rate of disappearance of an organism with time.

DISTRIBUTION CURVE—SPATIAL—A pictorial representation of the distribution out in space from a fixture.

EPIDEMIC DISEASE—One in which a large number of cases develop in a community within a short time. Dependent upon group susceptibility to a communicable or contagious disease. ENDEMIC DISEASE—One that is occurring constantly in isolated cases in a community. PANDEMIC DISEASE —An epidemic disease of widespread distribution.

EPIDEMIOLOGY—The science or study of epidemics.

ESCHERICHI COLI. E.Coli (B.Coli)—Normal bacterial inhabitant of animal colon. Harmless when air-borne and used as test organism because similar to respiratory disease organisms in resistance to ultraviolet and can be separated from the air-borne organism by selective media on Petri dishes. In water indicates sewage contamination.

EQUIVALENT AIR CHANGE—In sanitary ventilation a killing or removal of bacteria equivalent to the dilution of an air change—removes 63.2% of original air and any contaminant.

ERG—Unit of energy used in laboratory work—equals 1/10 ultraviolet microwatt-second.

EXPOSURE—Product of irradiation and time. Unit—uv-watt minute per sq. ft. or uv-foot-watt minute per cu. ft.

FOOT-LETHE — cubic-foot-lethe — square-foot-lethe. See LETHE.

GERMICIDAL TUBE—A source of shortwave ultraviolet—2000—3000A.

GERMS—A common term for pathogenic or disease-causing organisms—bacteria viruses, fungi, etc.

GLYCOL—PROPYLENE AND TRIETHYLENE—A chemical which acts as a lethal agent against air-borne bacteria when in the vapor form.

HEMOLYTIC STREPTOCOCCI—Round bacterial cells occurring in pairs or chains, secreting a substance which has the ability to disintegrate red blood cells. ALPHA HEMOLYTIC STREPTOCOCCI—Members of this group are usually not pathogenic. BETA-HEMOLYTIC STREPTOCOCCI—Members of this group are usually pathogenic.

IRRADIATION—Incidence of radiation on a surface or through a space. Unit—uv-watt per square ft. or uv-foot-watt per cu. ft.

ISO-INTENSITY LINES—A series of lines each representing out in space all the equal intensity points in any given plane from a source.

LETHAL EXPOSURE—Ultraviolet intensity and time for a 63.2% kill.

LETHE-unit of disinfection—Produced in air by one equivalent air change—63.2%. FOOT LETHE when in one cu. ft. of air also when on one sq. ft. of surface.

LOUVERS—Sheets of material arranged to intercept objectionable energy (usually directly from a source) with a minimum absorption of desired energy (usually from a reflector).

MICRON—A unit of linear measurement equal to one-millionth of a meter, or 39.37 millionths of an inch.

MILLIWATT PER SQ. FT.—Unit of intensity used in ultraviolet application engineering—equals 1.075 MICROWATT PER SQ. CM used in laboratory work. In air the unit is MILLIWATT-FOOT PER CU. FT.

MOLDS—A group of micro-organisms which reproduce by means of certain bodies known as spores. Widespread distribution and most often found as a contaminant. Certain molds are used in the production of antibiotics and in the manufacture of cheese.

OZONE—An active, unstable form of oxygen produced in air by ultraviolet energy of wavelengths less than 2000A and by electric discharges.

PATHOGENICITY—The ability of an organism to cause a disease.

PETRI DISH—Standard glass dish used for growing colonies of bacteria—named after first user. Flat, circular, 4 in. diameter, 5/8 in. high.

RADIATION—A germicidal tube *radiates radiation* and *irradiates* surrounding air or surfaces. Unit is ultraviolet-watt.

RESPIRATORY DISEASES — Diseases caught by breathing contaminated air but not necessarily diseases of the nose, throat or lungs. They may also be spread and caught in other ways.

SANITARY VENTILATION — Ventilation for air sanitation—bacterial reduction. See AIR SANITATION.

STAPHYLOCOCCI—A group of round-shaped bacteria usually appearing in clusters. Some members found in acne, boils and carbuncles. Normally found on skin.

STREPTOCOCCI—A group of bacteria, round in shape and usually appearing in chain-form. Some of these cause such diseases as Scarlet Fever, Septic sore throat, etc. See ALPHA-HEMOLYTIC.

ULTRAVIOLET—Radiant energy of wavelength below visible energy.

Erythemal U.V.—Ultraviolet radiation that produces erythema or reddening of skin.

Germicidal U.V.—Ultraviolet that has ability to kill bacteria.

VENTILATION—The bringing of fresh air into a room for temperature, humidity, odor, vapor, bacterial control.

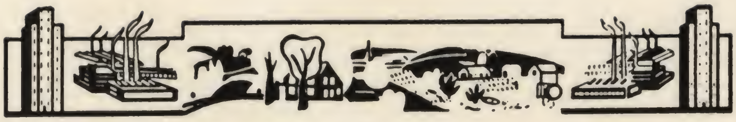
VIRULENT-INFECTIOUS—Able to overcome the defense mechanism of the host. It is the degree of invasiveness of a pathogenic organism.

VIRUSES—Are organisms so small that they generally cannot be seen under the greatest magnification of the ordinary microscope. Because even the finest filtering material will transmit them these are often referred to as "filterable viruses."

YEASTS—Microscopic organisms growing as single cells which normally multiply by a process of budding. Some ferment sugars.

Acknowledgments

The writers acknowledge reference to the publications of Dr. Matthew Luckiesh and Associates and the assistance of I. Matelsky in the preparation of this bulletin.



Sanitation is a way of life. It is the quality of living that is expressed in the clean home, the clean farm, the clean business and industry, the clean neighborhood, the clean community. Being a way of life it must come from within the people; it is nourished by knowledge and grows as an obligation and an ideal in human relations. THE NATIONAL SANITATION FOUNDATION

LAMP DEPARTMENT

GENERAL ELECTRIC COMPANY

SALES DISTRICTS (To Obtain Sales and Technical Information)	(Zone)		CITY	SERVICE DISTRICTS (To Order Lamps and to Obtain Shipping and Accounting Information. Local Warehouse Stocks maintained at these Points)	(Zone)	
8 Elk Street	7	3-4447	ALBANY, N. Y.	Buffalo Serv. Dist., 98 Hydraulic St., Buffalo 10, N. Y.		
187 Spring St., N. W.	3	WAlnut 9767	ATLANTA, GA.	680 Murphy Ave., S. W.	—	AMh'rst 5756-7-8-9
101 No. Charles St.	1	MUlberry 7733	BALTIMORE, MD.	Philadelphia Serv. Dist., 32nd & Walnut Sts., Phila. 4, Pa.		
50 High St.	10	HAncock 6-1680	BOSTON, MASS.	27 Burlington Ave.	15	COm'w'th 6-0215
901 Genesee Bldg.	2	CLeveland 3400	BUFFALO, N. Y.	98 Hydraulic St.	10	MOhawk 0800
516 Johnston Bldg.	2	4-8614	CHARLOTTE, N. C.	Atlanta Serv. Dist., 680 Murphy Ave., S. W., Atlanta, Ga.		
231 So. LaSalle St.	4	DEarborn 2-4712	CHICAGO, ILL.	431 W. Pershing Rd.	9	BOulevard 8-7100
230 So. Clark St.	4	DEarborn 2-4712	CHICAGO, ILL.	431 W. Pershing Rd.	9	BOulevard 8-7100
36 E. Fourth St.	2	DUnbar 2460	CINCINNATI, OHIO	Cleveland Serv. Dist., 1133 E. 152nd St., Cleveland 10, Ohio		
1320 Williamson Bldg.	14	CHerry 1-1010	CLEVELAND, OHIO	1133 E. 152nd St.	10	LIberty 1-1700
1801 North Lamar St.	2	Central 7711	DALLAS, TEXAS	1801 North Lamar St.	2	Central 7711
301 Davenport Bank Bldg.	—	2-2646	DAVENPORT, IOWA	St. Louis Serv. Dist., 710 No. Twelfth Blvd., St. Louis 1, Mo.		
1863 Wazee St.	2	MAin 6141	DENVER, COLO.	1863 Wazee St.	2	MAin 6141
1400 Book Tower	26	WOodward 3-6910	DETROIT, MICH.	1448 Wabash Ave.	16	WOodward 2-9650
820 Fisher Bldg.	2	TRinity 4-1400	DETROIT, MICH.	1448 Wabash Ave.	16	WOodward 2-9650
1811 Nat'l Stan'd Bldg.	2	PReston 4291	HOUSTON, TEXAS	Dallas Serv. Dist., 1801 No. Lamar St., Dallas 2, Texas		
1115 Circle Tower	4	MArket 2536	INDIANAPOLIS, IND.	Chicago Serv. Dist., 431 W. Pershing Rd., Chicago 9, Ill.		
200 East 16th Ave.	16	NOrclay 3568	N. KANSAS CITY, MO.	200 East 16th Ave.	16	NOrclay 3568
601 West Fifth St.	13	MIchigan 8851	LOS ANGELES, CALIF.	1855 Industrial St.	21	TUcker 2463
1179 Morehead St.	7	38-1441	MEMPHIS, TENN.	1179 Morehead St.	7	38-1441
5032 Plankinton Bldg.	3	MArquette 8-8580	MILWAUKEE, WIS.	Chicago Serv. Dist., 431 W. Pershing Rd., Chicago 9, Ill.		
500 Stinson Blvd.	13	GRanville 7286	MINNEAPOLIS, MINN.	500 Stinson Blvd.	13	GRanville 7286
744 Broad St., Room 606	2	MArket 3-3953	NEWARK, N. J.	133 Boyd St.	3	BIgelow 3-4500
185 Church St.	10	5-9828	NEW HAVEN, CONN.	Boston Serv. Dist., 27 Burlington Ave., Boston 15, Mass.		
570 Lexington Ave.	22	PLaza 5-6300	NEW YORK, N. Y.	Newark Serv. Dist., 133 Boyd St., Newark 3, N. J.		
1614 Campbell St.	7	HIghgate 4-7340	OAKLAND, CALIF.	1614 Campbell St.	7	HIghgate 4-7340
1405 Locust St.	2	KIngsley 5-3336	PHILADELPHIA, PA.	32nd and Walnut Sts.	4	EVerg'n 6-9600
535 Smithfield St.	22	GRant 1-3272	PITTSBURGH, PA.	601 E. General Robinson St.	12	FAirfax 1-9973-4-5
1238 N. W. Glisan St.	9	BEacon 2101	PORTLAND, ORE.	1238 N. W. Glisan St.	9	BEacon 2101
Southern States Bldg.	19	3-2893	RICHMOND, VA.	Philadelphia Serv. Dist., 32nd & Walnut Sts., Phila. 4, Pa.		
202 Hoge Bldg.	4	SEneca 8300	SEATTLE, WASH.	Portland Serv. Dist., 1238 N. W. Glisan St., Portland 9, Ore.		
710 No. Twelfth Blvd.	1	CHestnut 8920	ST. LOUIS, MO.	710 No. Twelfth Blvd.	1	CHestnut 8920
409 East Cass St.	2	2-2269	TAMPA, FLA.	Atlanta Serv. Dist., 680 Murphy Ave., S. W., Atlanta Ga.		

General Offices, Nela Park, Cleveland 12, Ohio

Bulletin LD-11 Printed in U. S. A. Revised January, 1950